PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by M. Davies

and Published by the Society

Hobart

Tasmania

28 NOVEMBER 2008

VOLUME 142

MUSEUM VICTORIA
29 APR 2009

PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by Margaret Davies

Published by the Society

Hobart

Tasmania

Graphic Impressions

ISSN 0080-4703

NOVEMBER 2008

VOLUME 142, PART 2

ROYAL SOCIETY OF TASMANIA

Council and Office Bearers from March 2008 to March 2009

Patron
His Excellency the Honourable Peter Underwood AO
Governor of Tasmania

President
Dr John Morris

Vice President
Mr Peter Stevenson

Immediate Past President
Professor J M Hunn

Honorary Secretary
Dr John Thorne

Honorary Treasurer
Dr Albert Goede

Assistant Treasurer
Mr Leon Atkinson-MacEwen

Councillors
Mr Bill Bleathman
Dr Ken Milton
Mr Jim Paterson
Ms Mary Koolhof
Mr Warren Boyles
Mr Leon Atkinson-MacEwen

Honorary Editor
Dr Margaret Davies

Honorary Librarian
Graeme Rayner

Statements of opinions expressed in papers in this volume reflect the views of the author(s) and are not necessarily those of the Royal Society of Tasmania.

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 142, PART 2

Contents

page

Kiernan, K. & McConnell, A. — Periglacial processes on Heard Island, Southern Indian Ocean 1

Pemberton, D., Gales, S., Bauer, B., Gales, R., Lazenby, B. & Medlock, K. — The diet of the Tasmanian Devil, *Sarcophilus harrisii*, as determined from analysis of scat and stomach contents 13

Sutherland, F.L., Barron, B.J., Pogson, R.E., Everard, J.L., Forsyth, S.M. & Hollis, J.D. — Unusual pegmatoid crystallisations in a nephelinite plug, near Round Lagoon, eastern Central Plateau, Tasmania 23

Osborn A.W., Forteath, G.N.R. & Stanisic, J. — A new species of freshwater sponge (Porifera:Spongillidae) of the genus *Radiospongilla* from Lake Pedder in Tasmania 39

Dartnall, H.J.G. — Antarctic vignettes I: Mawson's sailmaker – James Forbes 45

Dartnall, H.J.G. — Antarctic vignettes II: The search for S. Tasman, AB, on the *Terra Nova*, 1903–04 47

Kantvilas, G., Elix, J.A. & Jarman, S.J. — A contribution to an inventory of lichens from South Sister, northeastern Tasmania ... 49

de Little, D.W., Foster, S.D. & Hingston, T.L. — Temporal occurrence pattern of insect pests and fungal pathogens in young Tasmanian plantations of *Eucalyptus globulus* Labill. and *E. nitens* Maiden 61

Nicolle, D., Potts, B.M. & McKinnon, G.E. — *Eucalyptus cordata* subsp. *quadrangulosa* (Myrtaceae), a new taxon of restricted distribution from southern Tasmania 71

Johnson, K. A., Whinam, J., Buchanan, A. M. & Balmer, J. — Ecological observations and new locations of a rare moss, *Ambuchanania leucobryoides* (Ambuchananiaceae) 79

Trappe, J.M., Bougher, N.L., Castellano, M.A., Claridge, A.W., Gates, G.M., Lebel, T. & Ratkowsky, D.A. — A preliminary census of the macrofungi of Mt Wellington, Tasmania – the sequestrate species 85

Instructions to authors 97

Tasmania
Explore the possibilities

UTAS

Publication of this volume was supported by the Government of Tasmania and the University of Tasmania.

PERIGLACIAL PROCESSES ON HEARD ISLAND, SOUTHERN INDIAN OCEAN

by Kevin Kiernan and Anne McConnell

(with four text-figures, ten plates and one table)

Kiernan, K. & McConnell, A. 2008 (28:xi): Periglacial processes on Heard Island, Southern Indian Ocean. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 1–12. ISSN 0080-4703. Nature Conservation Research Group, School of Geography & Environmental Studies, Private Bag 78, University of Tasmania, Hobart, Tasmania 7001, Australia (KK*, AM). * Author for correspondence. Email: Kevin.Kiernan@utas.edu.au

Periglacial activity on Heard Island is manifested by intense physical weathering of the longest-exposed surfaces, and hillslope forms produced by a variety of cold-climate mass wasting processes. Microrelief features include rudimentary sorted steps, terraces and polygons. No evidence of deep cryoturbation was obtained from excavations at 14 sites in moraines and no landforms indicative of discontinuous permafrost were identified. Periglacial landform development has been inhibited by the maritime climate and is more restricted than on other islands in the region due to the low altitude of the ice-free terrain, limited extent of glacier-free ground, and relatively recent deglaciation.
Key Words: periglacial processes, cryoturbation, frost action, sorted polygons, sorted terraces, climatic warming.

INTRODUCTION

Improved understanding of periglacial processes in the southern Indian Ocean is important because the maritime sub-Antarctic environment is very different from northern hemisphere periglacial environments from which most concepts in periglacial geomorphology have been developed. In contrast to the continental interiors of the northern hemisphere, the periglacial climate on sub-Antarctic islands is characterised by a low annual temperature range, cloudy skies, high precipitation totals and freeze-thaw events that are of high frequency but penetrate to only shallow depth. Thus, this environment has more in common with high tropical mountain summits than with the classical periglacial environments of northern hemisphere continental interiors (French 2007, Boelhouwers *et al.* 2003).

An extensive assemblage of periglacial landforms produced by frost action and other cold-climate processes has been recorded from the southern Indian Ocean islands of Marion (Hall 1979a, b, 1981, 1983b, Boelhouwers *et al.* 2003), Crozet (Bellair 1969a, b) and Kerguelen (Aubert de la Rue 1959, Nougier 1964, 1972, Bellair 1969a, b, Markov 1971, Hall 1983a, b). However, a recent review by Hall (2002) was limited to a single paragraph on the likely extent of periglacial landform development and periglacial processes on Heard Island, because while the existence of some periglacial landforms has previously been recorded (Colhoun & Peterson 1986, Kiernan & McConnell 1999, Bergstrom & Selkirk 2000), no detailed descriptions or overview of the range of periglacial phenomena present has hitherto been available. This is a serious deficiency because Heard Island is distinctive for being the only large island in the region that lies south of the Antarctic Convergence. The purpose of the present paper is to provide the first systematic reconnaissance and interpretation of periglacial phenomena from this important site.

Heard Island (area 368 km², 73°32'E, 53°06'S) is dominated by the 20-km-wide active Big Ben volcano (2745 m). Around the lower flanks of Big Ben are smaller subsidiary cones (Stephenson *et al.* 2006), and another volcanic complex, on Laurens Peninsula (715 m), projects ~10 km northwestwards (fig. 1). Most of the island is glacier-covered (Ruddell 2006) and apart from isolated rocks and buttresses on some upper slopes and Laurens Peninsula, glacier-free terrain is largely confined to below 250 m. It consists primarily of moraines and glaciofluvial aprons, coastal deposits of sand to boulder size, aeolian sediments, and ice-abraded basalt bedrock and diamictites within the Late Miocene–Early Pliocene Drygalski Formation (Truswell *et al.* 2005). Vegetation cover, mostly cushion carpet and tussock grassland, is generally confined below 100 m. The largest area of relatively gently-sloping land above this altitude is South Plateau, which is thus of particular interest for potential periglacial phenomena. However, significant glacier recession over recent decades is exposing additional areas of new bare ground (Ruddell 2006).

Periglacial Climate

Projecting high into the westerly airstream of the "Furious Fifties", Big Ben exerts a major influence on local weather. Climatic data obtained from Atlas Cove from December 1947 until March 1955 revealed a mean annual air temperature of ~1.2°C (seasonal variation ~4.5°C, maximum 14°C, minimum –9°C). Average annual precipitation was 1350 mm, with precipitation occurring on 300 days per year and totals greatest in late summer and early autumn, when rain dominated over snow at low altitudes. Mean sea-level wind speed was 26 km/hr (maximum 209 km/hr) (Allison & Keage 1986). More recent temperature data from automatic weather stations (AWS) indicate the coldest and warmest temperatures occurred at Spit Bay (–8.4°C, 20 September 1997; 25.3°C, 23 June 1998) (D. Thost pers. comm.). The highest temperatures were of short duration and were associated with foehn winds (Ruddell 2001). A total of 60–80 atmospheric freeze-thaw cycles annually is evident from the AWS data (table 1). They were caused more by cyclonic disturbances than diurnal influences, and temperatures below 0°C rarely lasted more than a few hours at sea level (Thost & Allison 2006). Significant climatic warming over recent decades has been manifested

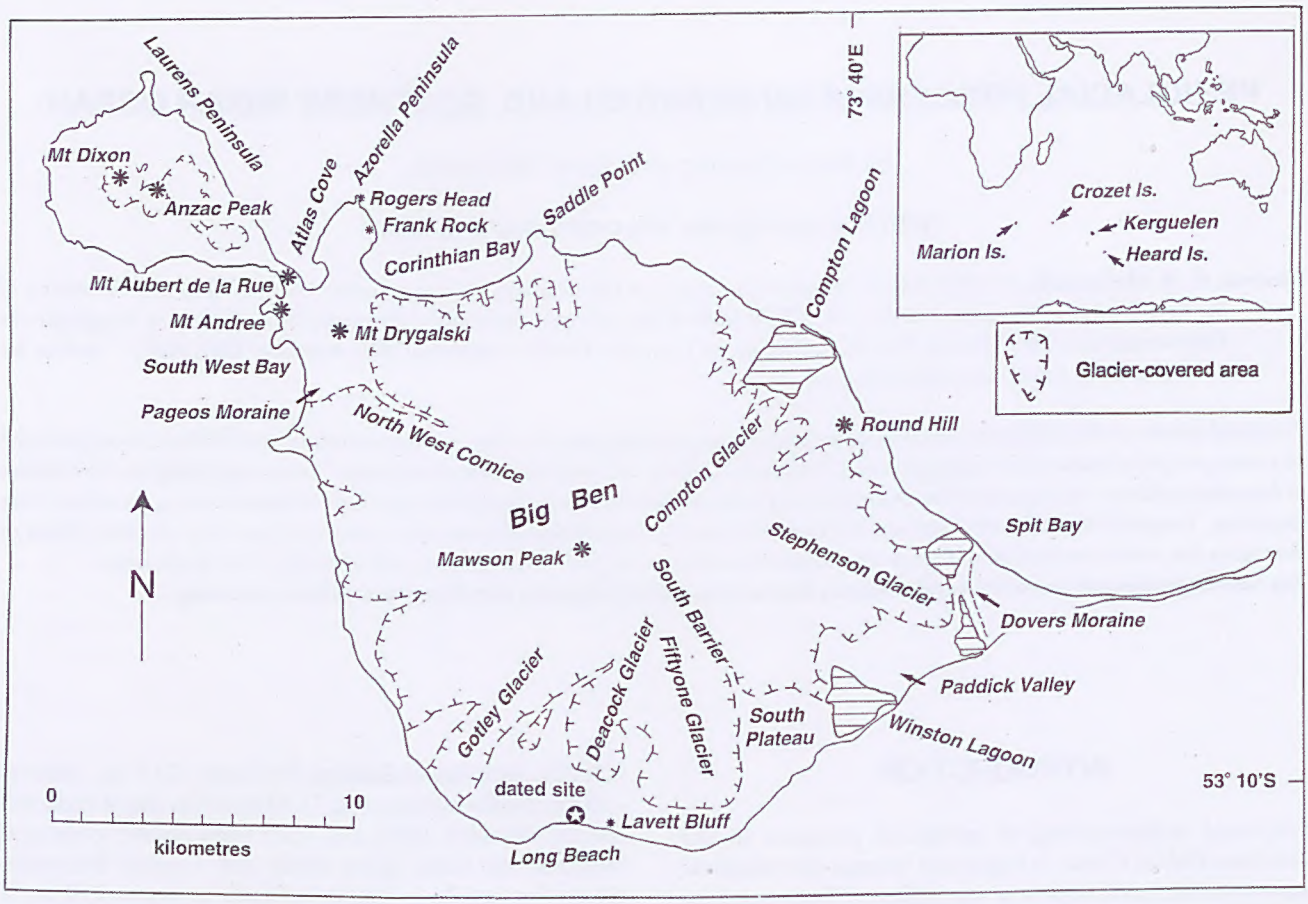


FIG. 1 — Location of Heard Island and sites referred to in the text.

TABLE 1
Atmospheric freeze–thaw cycles, 1997–2000*

	ATLAS COVE					SPIT BAY				
	1997	1998	1999	2000	2001	1997	1998	1999	2000	2001
Jan	nd	0	0	0	0	nd	0	0	0	0
Feb	nd	0	0	0	0	nd	0	0	0	0
Mar	nd	0	0	0	0	nd	1	0	0	0
Apr	1	0	0	5	0	0	2	2	3	1
May	1	5	4	2	8	3	7	3	4	11
Jun	6	11	9	12	10	11	9	12	10	15
Jul	5	5	12	12	nd	8	11	16	10	nd
Aug	8	9	11	10	nd	11	12	11	9	nd
Sep	12	16	6	11	nd	12	11	9	10	nd
Oct	7	10	11	12	nd	10	9	14	10	nd
Nov	5	5	5	9	nd	7	4	10	12	nd
Dec	0	0	1	2	nd	0	0	2	1	nd
Total	(>?45)	61	59	75	(>18)	(>?62)	66	79	69	(>27)

* Based on climatic data supplied by D. Thost, Antarctic CRC, Hobart.
Record for Atlas Cove commences 18 April 1997, record for Spit Bay commences 1 April 1997.
nd = no data.

by a rise in the snow-line, longer melt season, rapid retreat of many glaciers, and major expansion of melt-lakes amid ice-cored moraines (Budd 2000, Kiernan & McConnell 2002). Using glacier-climate modelling Ruddell (2006) inferred warming by 0.8°C since the 1940s.

METHODS

This paper records reconnaissance surveys of periglacial landforms undertaken incidental to other fieldwork in March 1997 and November–December 2000. The relative ages of surfaces and sediments were interpreted from morphostratigraphic relationships between landforms and deposits, radiocarbon dating of organic material contained in sediments, and historical photographs and records (Kiernan & McConnell 2002). Field measurements of the dimensions and orientation of landforms, and sediment stratigraphy, were obtained using a hand-held clinometer, compass, tape and staff, and locations were recorded by GPS. Small pits of maximum 60 cm depth were excavated at 14 sites on moraines to enable inspection of cryogenic disturbance and the degree of clast weathering and pedogenic alteration of the sediments. To explore surface weathering rates, the morphometry of surface clasts of 4–10 cm diameter from sites on Dovers Moraine (fig. 1) was determined by the methods of Kuenen (1956) and Sneed & Folk (1958) and compared to that of shallow subsurface samples from the same sites. Ground ice classification follows Pihlainen & Johnston (1963). Approximations of excess ice content in sediments are based on estimated volume of supernatant water in sample bags that were thawed in the laboratory. Interpretations of the periglacial environment responsible for formation of the observed landforms are based on climate data obtained up to the time the fieldwork was conducted, so as to minimise any potential distortions resulting from the most recent climate warming.

RESULTS AND DISCUSSION

Physical weathering features

Scree along the northern slopes of Laurens Peninsula, below South Barrier, and elsewhere, attests to effective physical weathering. Trachyte on Mt Andree has been shattered into plates generally <40 cm long (maximum >1 m) and up to 20 cm thick (pl. 1). The lavas of Azorella Peninsula and Mt Dixon are less heavily shattered than adjacent pyroclastic residuals such as Rogers Head and Frank Rock. Evidence of physical weathering appears to be confined to shattering, and no granular disintegration suggestive of salt weathering was observed despite the highly maritime setting, nor were significant discolourations or salt efflorescence observed.

The significance of frost action to overall physical weathering is not always clear because some rock types appear particularly susceptible to other processes that cause disintegration (Whalley *et al.* 1982). For example, rare clasts of felsic basalt on Dovers Moraine are heavily shattered although more mafic basalt clasts in close proximity remain intact (pl. 2). The shattered clasts occur in areas deglaciated only during recent decades and they could not have rolled downslope from older moraines. One clast had broken down into flat, straight-edged flakes 1–4 cm thick, <10 cm long and ~6 cm wide with another fragmented into blocks and shells rather than tabular flakes, the debris strewn 20–30 cm outside the shadow of the original ~50 cm clast. Crack propagation does not appear due solely to freeze-thaw so much as to a predisposition to weathering imparted by mineralogy and fabric and probably involving breakdown of feldspars.

Freeze-thaw cycles at ground level are likely to be nearly twice as numerous as atmospheric cycles, hence, >100 cycles at ground level are likely on Heard Island (French 2007). Nevertheless, relatively limited frost shattering of recent glacial boulders is to be anticipated. A freeze amplitude of –3°C is regarded by McGreevy & Whalley (1982) as a threshold for effective mechanical weathering. Short-duration atmospheric freeze-thaw cycles of this amplitude were experienced at Atlas Cove only 11 times and at Spit Bay only 24 times between 1997 and 2000 (table 1).

To explore the possibility of more subtle physical weathering effects, morphometry of surface clasts was examined along a transect across the Dovers Moraine complex. To reduce the risk that apparent differences between sites might simply be the product of differences in original clast shapes, morphometry of shallow subsurface clasts was compared to that of the surface clasts from the same locations. Three moraines were compared: (1) immediately adjacent to the 1997 edge of the Stephenson Glacier; (2) midway across the complex, believed to have been deposited within the past 50 years; and (3) a small push moraine on

PLATE 1
Shattered trachyte at ~50 m altitude on southeastern slopes of Mt Andree.

PLATE 2
Shattered clast of felsic basalt amongst unweathered, less felsic clasts at Dovers Moraine.

the outer margin of the main complex, believed to have been deposited prior to 1850 but within the past two millenia (Kiernan & McConnell 2002). Comparisons were restricted to mafic clasts in order to minimise the risk of differences in mineralogy causing results to depart from a time-dependent sequence.

Clasts being deposited at site 1 were assumed to be essentially unweathered given their fresh appearance and the very recent age of this moraine (Kiernan & McConnell 2002) hence surface and subsurface samples were not differentiated. Contrasts in morphometry between surface and subsurface clasts are discernible at the other sites (fig. 2), but while mean values for rounding and sphericity of surface samples from sites 2 and 3 proved slightly lower than for the subsurface samples, they overlap at one standard deviation at each site and between sites (roundness 0.25–0.34, sphericity 0.72–0.81). Overall, the results suggest that physical weathering on the surface may have caused subtle morphometric changes to surface clasts within a few decades.

Slight rounding of subsurface clasts detected in a number of our excavated soil pits elsewhere on Heard Island, together with minor discolouration and pitting of clast surfaces, suggests subsurface chemical weathering is also occurring at some sites. Such apparent rapidity of chemical weathering was not anticipated in this environment but other evidence of relatively rapid chemical weathering was also observed, including minor karren formed on limestone southwest of Anzac Peak on Laurens Peninsula. A vegetation cover of sedge and occasional *Azorella selago* Orchard allows the involvement of biogenic acids on Laurens Peninsula. Small weathering pans on unvegetated basalt surfaces inland of Winston Lagoon that have been exposed for only a few decades suggest some rock dissolution by snow meltwater.

Hillslope forms and processes

Steep faces from which debris has been liberated are generally relict from glaciation, volcanism, volcanigenic debris avalanching or coastal erosion. The profile of the debris zone is often concave-upwards and incised by shallow depressions and sharper-edged channels suggestive of debris flows and fluvial incision respectively. The smoothest debris-mantled slopes typically rest at <15° but in some places up to 22°. Snow accumulates on them and meltwater plays an important role in causing surface wash.

Lambeth (1950) recorded a stake placed in sediments between Corinthian Bay and Mt Drygalski having moved 4.6 m seaward in 11 months, suggesting that solifluction was active at that time. Terraces and lobes that locally form patterned ground are described below. Effective nivation is suggested by unvegetated till at sites of persistent snow cover amid otherwise vegetated terrain east of Dovers Moraine and elsewhere.

Movement of particles by rainsplash was witnessed on slopes devegetated by penguin traffic on Mt Aubert de la Rue. Exposed regolith is susceptible to slopewash. Broad planar slopes above small alluvial fans attest to the efficacy of sheetwash, while rills are also pronounced in some areas. Less compact material encountered in the uppermost part of some excavated inspection pits, together with silt caps on clasts in some profiles, attest to subsurface wash. In periglacial environments such silt caps are typically associated with infiltration beneath snow (Corty *et al.* 1989).

Rapid mass movement occurs at a number of scales, commonly at sites left unstable by glacial processes. Rubble below large bedrock slabs delineated by major fractures that extend over 100 m along the valley wall east of the Compton Glacier terminus is attributable to stress release following glacier retreat (Harland 1957).

Rockfall is common but talus accumulation inland is inhibited by debris being removed by glaciers, although small talus cones occur beneath South Barrier and North West Cornice. Debris cones below cliffs at Laurens Peninsula and Round Hill slope at up to 30°.

Snow avalanches from Big Ben were heard and occasionally witnessed but dissipated on snow or glacier slopes and no geomorphological effects were recognised. At a much smaller scale, initial summer thawing of aeolian sediment in the lee of rock ridges at the foot of Mt Drygalski was observed to trigger downslope glissade of ice cemented slabs ~10 cm thick and up to 30–40 cm wide (pl. 3).

Large terraces with treads sloping at 5–7° and mantled by small angular rock fragments occur between bedrock outcrops on South Plateau. They lack the long narrow form typical of cryoplanation terraces and like many other surfaces they appear to be formed on bedrock and to owe their form to lava flow morphology or glacial erosion.

Gulleys and alluvial fans attest to effective sediment movement during summer rainstorms and by meltwater released from ice-cored moraines or glaciers. Subfossil sedge obtained from silts beneath 2.5 m of vegetated glaciofluvial sediments on the ice-distal side of the westernmost moraine of Deacock Glacier at Long Beach (altitude 4.2 m) have been radiocarbon dated to 220±113 ^{14}C yrs BP (Wk 9485) (fig. 3). This indicates that a period of relative stability, during which sedge grew on relatively fine-grained sediments, was followed by instability and rapid sedimentation within the past two centuries prior to colonisation by the present-day plant cover. Many other presently stable extraglacial surfaces may be equally youthful.

Periglacial microrelief features

Stone polygons up to 8 m diameter occur at the southern base of Anzac Peak (Bergstrom & Selkirk 2000) but sorted polygons are otherwise only weakly developed. Among the better formed are debris islands 30–40 cm high on ice-cored moraines at 210 m altitude on the western side of Round Hill. They have elevated cores 40–70 cm in diameter that consist of sand and fine gravel with larger clasts to <6 cm. Their coarse borders are 40–50 cm wide comprising clasts typically of <20 cm (maximum ~70 cm diameter), smaller clasts tending to stand on edge (pl. 4).

Sorted polygons formed on older till that lacks an ice core are more rudimentary. Along the northern coastal fringe examples occur on low angled (<7°) east-facing slopes atop Round Hill, where slightly convex cores 30–40 cm wide comprise primarily sand and small pebbles of <0.5 cm, flatter clasts being essentially flat-lying. Coarse borders are typically 15–30 cm wide, formed from clasts generally <10 cm (maximum ~30 cm) with most clasts too spherical to discern any tendency to be standing on edge. Incipient stone stripes on the cores of the polygons parallel both wind direction and slope angle. Other incipient polygons occur on till above the coastal cliffs just to the north and at 152 m altitude above the vegetated moraines southeast of Compton Lagoon. On the southern side of Heard Island, a few very rudimentary polygons occur on a <5° slope at

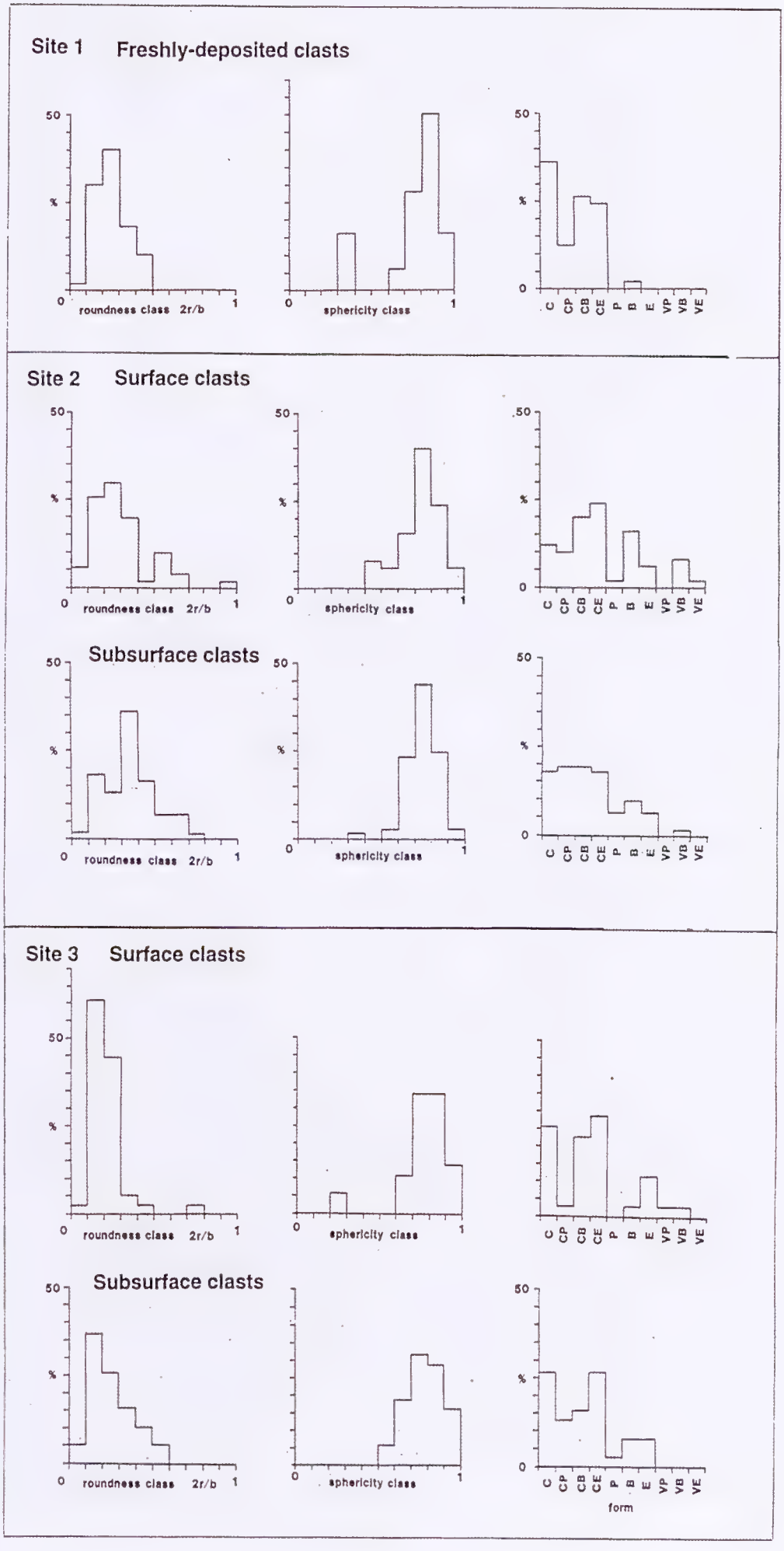


FIG. 2 — Frequency distribution for roundness, sphericity and form of recently-deposited till clasts from site 1 (A) and comparison with older tills at site 2 (B= subsurface, C= surface); and site 3 (D= subsurface, E= surface). Form classes: C= compact; P= platy; B= bladed; E= elongated; V= very.

PLATE 3
Small-scale slope instability triggered by superficial thawing of frozen aeolian sediments below Mt Drygalski, involving glissade of ice-cemented slabs ~10 cm thick and 30–40 cm wide.

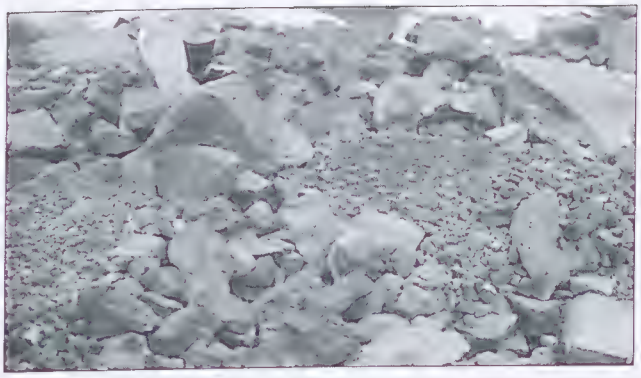


PLATE 4
Debris islands formed on ice-cored moraines at 210 m on the western side of Round Hill.

~260 m altitude on South Plateau. Cores are 100–150 cm wide, comprising fine gravels (largest clasts <8 cm). Coarse borders, sometimes marked by a subtle hollow, are 30–50 cm wide and comprise clasts generally <15 cm diameter (maximum ~30 cm).

Rudimentary sorted stone stripes on South Plateau are formed from sediments of similar calibre to the polygons but they occur on slightly steeper slopes. Better-developed stripes occur on north-facing 22° slopes of Round Hill (380 m altitude) where coarse borders ~10 cm wide formed from clasts of generally <2cm (maximum ~10 cm) separate irregular sandy stripes ~60 cm wide that have occasional small pebbles on their surface (pl. 5). Sorted stripes have also been recorded from scoria and ash/sand slopes at the northern base of Mt Dixon (Bergstrom & Selkirk 2000).

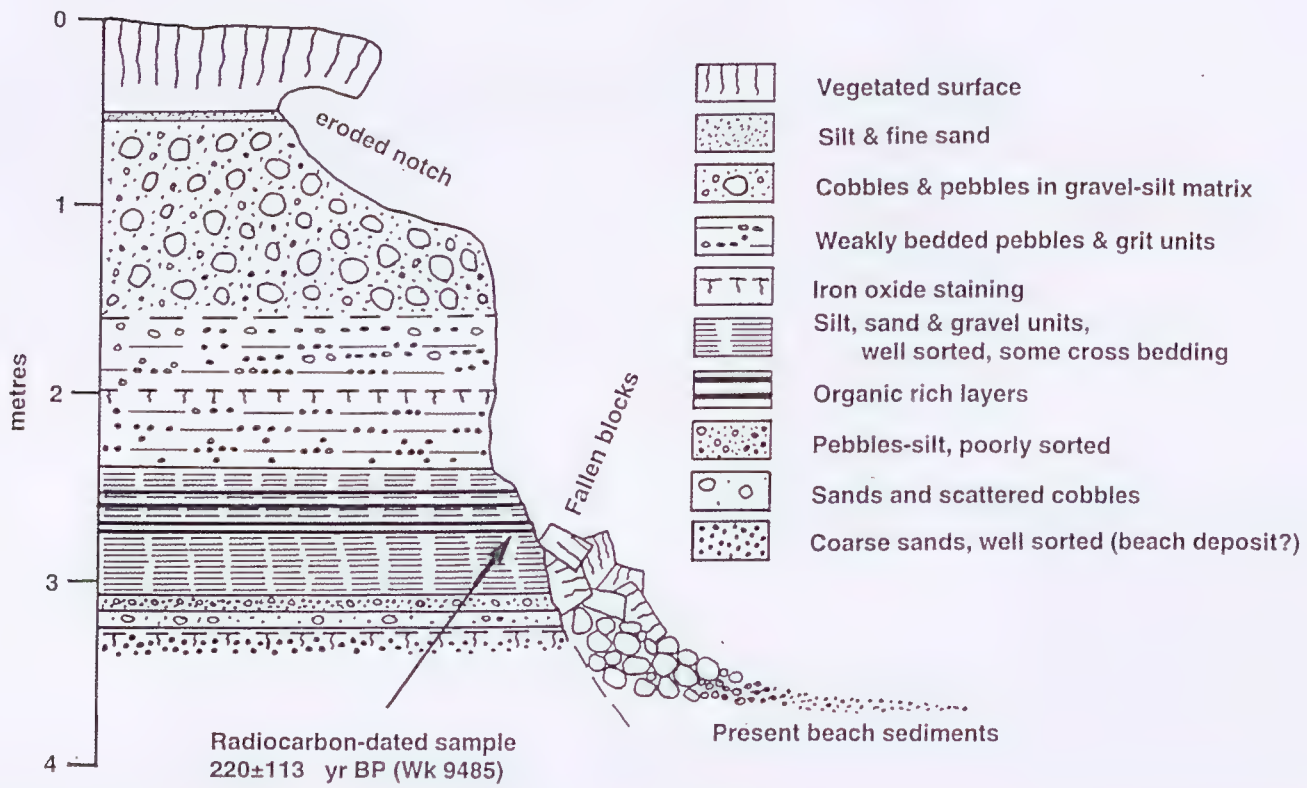


FIG. 3 — Stratigraphy of glaciofluvial sediments on the foreshore at Long Beach, external to the outermost western moraine of the Deacock Glacier.

PLATE 5
Rudimentary sorted stripes on Round Hill.

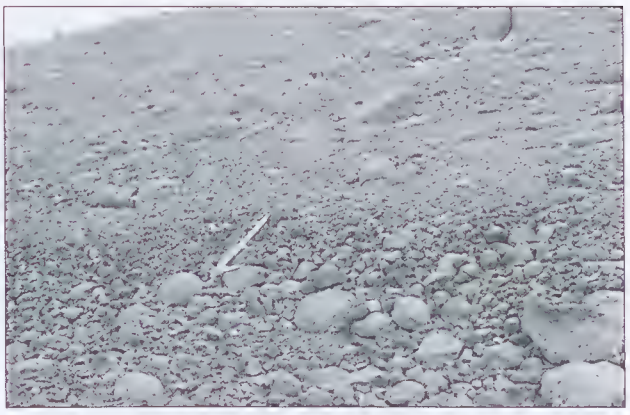


PLATE 6
Small stone-banked terraces on west-facing till slopes near the summit of Round Hill.

PLATE 7
Vegetation-banked terraces on Mt Andree.

Weakly-developed unvegetated stone-banked terraces occur on west-facing moraine slopes near the summit of Round Hill (pl. 6). One sequence of 16 terraces comprised treads ≤1.5 m wide extending up to 3–4 m along the hillside and sloping at ~7–15°, separated by risers 40–50 cm high sloping at ~25–45°. Tread sediment had a calibre of <2 cm with clasts of generally no more than 6 cm (maximum 40 cm) diameter forming the risers. Similar terraces occur on the northeastern and southeastern summit slopes of Round Hill. Slightly better-developed examples occur east-southeast of the summit. The best developed flight occurs over an altitudinal range of ~20 m on a south-facing slope. The dominance of terraces over lobate forms suggests that frost creep rather than gelifluction is the most active process (French 2007).

Vegetation-banked terraces are more common (pl. 7). On slopes <10° on Mt Andree, where vegetation cover may locally exceed 50%, their treads are generally <100–150 cm wide (slope <5°) and the risers 20–30 cm high (slope 2–30°). On slopes of ~10°–15°, where vegetation is largely confined to risers, well-formed *Azorella*-banked terraces with treads formed mostly of clasts <3 cm (maximum generally <8 cm) extend around the contour. On steeper slopes (15–20°) terraces are narrower and oriented aslant the slope, and small fluvial channels extending downslope between terraces are common. Terrace alignment here is broadly parallel to dominant wind direction. Small notches at the back of some treads are consistent with localised aeolian and/or fluvial erosion focused at the foot of the *Azorella* riser. The shallow depth of these notches, disturbance of treads by pipkrake and alignment of terraces parallel to current wind direction all suggest that these terraces are active, their distribution and character influenced by slope materials and angle, substrate stability, moisture availability, wind and vegetation cover. Only isolated islands of vegetation occur on very steep slopes at Mt Andree.

Small pits, generally <40 cm long, 30 cm wide and 10–15 cm deep (maximum ~120 cm long and ~20 cm wide), were encountered on the broad plain below 20 m altitude between Mt Andree and Mt Drygalski in late October 2000, formed in sandy aeolian sediments with a thin lag of grit and fine gravel. Lag blown into pits is the likely origin of small pods of gravel in these sediments. Many pits were elongate parallel to aeolian ripples in the sediment. While they occur in an area utilised by burrowing birds, excavation revealed no evidence of burrows extending from their margins, hence they do not appear to have resulted from collapse of burrows. They are instead interpreted as having resulted either from melting of small segregated ice bodies that form seasonally or of snow that accumulated with aeolian sediment (pl. 8).

Cryoturbation phenomena

Some exposed ground surfaces are armoured by clasts up to cobble size and occasionally boulders. The most likely causes of armouring in a periglacial environment are either upfreezing of clasts or deflation. Upfreezing may occur either by a clast being gripped by the descending freezing plane then being pulled upwards during overall lifting, or because its thermal conductivity favours ice formation beneath it, pushing it upwards (French 2007). Migration of thawed finer material into the resulting void precludes its reoccupation by the

PLATE 8
Melt-pit formed in superficial aeolian sediments east of Mt Andree (width is 40 cm where crossed by staff).

PLATE 9
Split surface clast below Mt Drygalski.

PLATE 10
Ventifacted basalt boulders, southwestern corner of Atlas Cove.

raised clast after thawing. None of our excavated pits revealed thicker silt accumulations beneath clasts; instead, silt caps occurred on clasts at six sites and coatings around clasts in eight cases, but neither caps nor coatings in three other cases. Similarly, exploratory excavation to ~30 cm depth beneath a veneer of clasts generally <8 cm size (maximum ~15 cm) at the summit of Round Hill revealed only gritty sand with no accumulation of fine material beneath individual clasts. Hence, the stone veneers are interpreted as primarily lag following deflation.

There is locally abundant evidence of more superficial clast movement by frost action, notably rotation caused by frost pull on the upper edge of surface clasts as the freezing plane descends. Split surface cobbles with the fragments standing on their edge are common between Mt Drygalski and Laurens Peninsula and clasts standing on their edges were encountered in slope deposits at Round Hill and Mt Andree (b-axis inclination 25–40°) and at some excavated pit sites. One typical example below Mt Drygalski comprised a rounded cobble ~8 cm long split longitudinally, the fracture plane and b-axis standing vertical and the two halves separated by a gap of ~5 cm filled by aeolian sediment (pl. 9). This result is interpreted as the combined effects of physical weathering, fragment separation by frost action and sediment infill, and fragment rotation or support by frost push or pull. Frost heaving of bare moraine surfaces between cushions of *Azorella selago* has previously been noted by Bergstrom & Selkirk (2000) and was observed by us in several areas.

Minor involutions were observed on flat, saturated and unvegetated sandur inland of South West Bay. They were 10–20 cm high and generally less than 100 cm wide, comprising eruptions of subsurface fine sand and silt onto a surface of sand and fine gravels. More complex forms exhibited a central "crater" with a vertical sediment column forming a core. The regularity and simple form of most involutions, and their environmental setting, suggest that the implied plastic deformation of unfrozen sediment could be caused by cryostatic pressures. However, the presence of permafrost has not been confirmed, hence, pressure between seasonal downward freezing and deeper permafrost cannot be assumed. The formation of periglacial involutions may require more severe depression of ground temperatures than may occur on Heard Island. An alternative explanation for the Heard Island features is that they are the product of density differences, related to generation of high pore water pressures as ice melts. Hence, they may be normal load cast structures, formed due to a reduction in inter-particle friction in finer subsurface sediments beneath heavier gravels that exert downward pressure (French 2007).

Ground ice conditions

Segregated ground ice observed in excavated pits comprised pore ice and rare lenses a few tens of centimetres long and up to 1–2 cm thick. Under the descriptive system of Pihlainen & Johnston (1963) ice types encountered were predominantly non-visible ice (N) in well-bonded sediments (Nb) with generally limited excess ice (Nbe). Visible ice (V) in some excavations generally comprised individual ice crystals or minor inclusions (Vx) and ice coatings on particles (Vc). Excess ice content proved greatest in lee-slope cones of aeolian sand at the foot of Mt Drygalski. It was not measured accurately but was estimated at >50% from supernatant water in thawed sample bags.

Ice was encountered in only six inspection pits, primarily as lenses in units with slightly higher than normal silt or clay contents. On the northern side of the island ice cementation was encountered below 40 cm depth in a moraine at 64 m altitude east of Compton Lagoon and at 4 cm depth atop Round Hill (404 m altitude) in November 2000. On the southern side of the island very densely ice-cemented till was encountered immediately below the surface in a moraine at 132 m altitude adjacent to the Gotley Glacier, and clay/silt-rich till at 160 m altitude on nearby Lavett Bluff was also densely ice-cemented from the surface. In contrast, no ice core was encountered in 0.5 m deep excavations in less clay-rich supraglacial moraines at 193 m. These observations are consistent with colder conditions on the southern side of Big Ben and the presence of ice at variable depth according to sediment texture and altitude.

Whether such occurrences represent permafrost or seasonal ice is unresolved. Aeolian sand accumulations northwest of Mt Drygalski remained densely ice-cemented below 20 cm depth in November 2000, but the extent to which this ice persists through summer is not known. Ice-cemented aeolian sands were encountered in the entrance to lava tube caves at <100 m altitude on Azorella Peninsula in March 1997. A permafrosted condition is suggested by the persistence of this ice at the end of the melt season.

Landforms indicative of permafrost, such as ice-wedge polygons, ice-cored mounds and pingos, and palsas or peat plateaus, were not recognised. No thermokarstic landforms indicative of permafrost degradation, such as ground-ice slumps, depressions, thaw lakes and beaded drainage systems, were recorded. Collapse pits in the Dovers Moraine complex are not of periglacial origin but have formed in response to melting of buried glacier ice.

Periglacial aeolian landforms

Spectacularly developed ventifacts occur at the western end of Atlas Cove where basalt boulders are subject to abrasion by windblown sediments derived from glaciofluvial and raised coastal deposits between Big Ben and Laurens Peninsula, and by windblown ice crystals. Boulders up to 1.5 m wide occupy ~30% of the ground surface, standing 40–60 cm above it, with freshly eroded basalt on their windward face and 60–80% lichen-cover on their leeward side (pl. 10). Small ventifacted clasts from Drygalski Formation sediments collected by P. J. Stephenson, are described by Sugden (1968). Some beach cobbles above the present limit of wave action on Elephant Spit are also ventifacted (fig. 4), as are a few glacial clasts on the Winston Lagoon barrier.

Wind-eroded swales flanked by retreating scarps up to 2 m high, in which numerous plant roots are exposed, occur amid vegetated ash and scoria at Saddle Point, on the northwestern extremity of Laurens Peninsula, and elsewhere. Behind the southern beach just east of Dovers Moraine is a 50-m-wide zone of exposed plant roots where vegetation and soil have been stripped by the wind, probably assisted by seals and penguins. This general area is a major source of sandstorms that sweep across the apex of Elephant Spit. Elephant seal harems along the northern side of this spit sometimes form a local "snow fence" that results in localised sand deposition, resulting in temporary islands of sand rising 1 m or more above the beach cobbles (Green 2000). Similar but smaller accumulations occur on the Winston Lagoon bar.

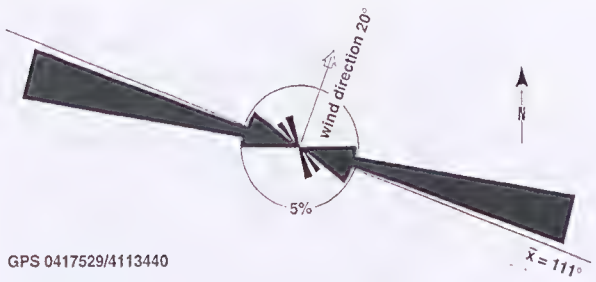


FIG. 4 — Orientation of crests on ventifacted beach cobbles midway across the apex of Elephant Spit (distance from HWM 130 m, altitude 2.2 m), indicating predominance of SSW winds (n=25).

INTERPRETATION OF THE PERIGLACIAL ENVIRONMENT

Only limited development of periglacial landforms has occurred on Heard Island. Classical indicators of permafrost, such as ice wedges, form in colder environments when exposed ground is cooled sufficiently to cause shrinkage of ice in the soil and cracking of the frozen ground. Subsequent freezing of meltwater in the voids perpetuates the cracks. If soil is sufficiently ice-rich, cracking can occur with a temperature drop of as little as 4°C in the below-zero range (French 2007). However, the coldest temperature recorded from glacier-free areas of Heard Island between 1997 and 2000 was only –8.4°C, much warmer than the temperatures of –15°C to –20°C generally considered necessary for ice wedge formation (French 2007).

The maritime environment of Heard Island is one factor that inhibits some forms of periglacial activity. Freeze-thaw action is inhibited by release of latent heat by summer melting of ground ice and rapid warming of the ground by snowmelt infiltration (French 2007). Winter snow cover combined with meltwater and liquid precipitation during summer moderates temperature fluctuations at the ground surface. Consistently cloudy conditions inhibit escape of long-wave radiation and also solar heating that might otherwise elevate ground temperature above atmospheric temperature. Latent heat is released as abundant liquid water freezes during autumn, again stabilising regolith temperatures.

There are broad similarities in the types of periglacial features present on Heard, Marion, Crozet and Kerguelen islands. For example, sorted nets are present on all four islands. However, they are markedly less common on Heard

Island. With the exception only of the polygons described from the southern base of Anzac Peak by Bergstrom & Selkirk (2000), the polygons on Heard Island are generally smaller than those described from Îles Kerguelen or Marion Island (Hall 1983b). A relative paucity of stone-banked and vegetation-banked terraces is not unique to Heard Island, for they are also rare on Îles Kerguelen compared to Marion Island. But overall, and notwithstanding its location south of the Antarctic Convergence, the range and development of periglacial landforms on Heard Island is much more limited than on the other islands.

Jacka & Ruddell (1998) concluded from model studies that the temperature record from Îles Kerguelen provided the best available proxy for Heard Island. Nevertheless, the number of atmospheric freeze-thaw cycles on Heard Island from 1998–2000 (60–80) was significantly less than recorded from Îles Kerguelen (120) by Aubert de la Rue (1959). Even allowing for the suggestion that ground frosts may be twice as numerous as air frosts, the number of ground frosts on Heard Island is likely to be less than the 200–236 recorded from Îles Kerguelen where maximum ground penetration of freeze-thaw cycles was still only 0.05 m (Aubert de la Rue 1959, Troll 1960, Hall 1983b). On Marion Island, air temperatures of –2°C or lower occur at sea level on 48 days/year (freeze amplitude 3.4°C) and on 111 days/year at 500 m altitude (mean freeze amplitude –4.1°C) (Hall 1979b). The number of precipitation days per year on Heard Island (300) is comparable to the number on Îles Kerguelen (334) and Marion Island (300).

Lesser development of periglacial landforms on Heard Island relative to other islands in the southern Indian Ocean cannot be attributed solely to climatic differences. Greater physical weathering of longer-exposed rock outcrops and more pronounced terrace development on Mt Andree than within any area deglaciated within the past two centuries indicates duration of exposure is a significant determinant of periglacial landform development on Heard Island. That the most pronounced sorted polygons occur on relatively recent moraines is probably due to the presence of unmelted ice cores that inhibit infiltration, and thereby facilitate generation of high cryostatic pressures in the till during seasonal freezing from the surface. The absence of such well-developed polygons from older moraines probably reflects ice core melting and reworking.

The periglacial landforms recorded from Heard Island are much less well-developed than those known from Australia's other major sub-Antarctic terrain, Macquarie Island (54°37'S, 158°54'E), where sorted stone circles up to 100 m in diameter and very well-developed terraces are present. This difference is despite Macquarie Island's broadly similar latitude to Heard Island and position north of the Antarctic Convergence. Whereas most of Heard Island has previously been glacier-covered, there is no evidence to suggest past glaciation of Macquarie Island, hence periglacial landforms have had much longer to develop on Macquarie Island, which has remained exposed through several Glacial Climatic Stages. However, the very well-developed terraces on Macquarie Island do not appear to be relict, Selkirk (1998) having recorded surface gravel movement of 38–148 mm/year on vegetation-banked terraces, facilitated by the presence of liquid water, frequently groundwater seepage.

The low altitude of most ice-free terrain on Heard Island (generally <250 m) is another limiting factor on the extent of its periglacial landforms. There is considerable ice-free terrain to over 800 m on Îles Kerguelen, while Îsles Crozet is glacier-free to its 1090 m summit and on Marion Island exposed ground occurs to ~1200 m. Similarly, Macquarie Island rises to 433 m. Development of periglacial landforms also appears to be partly a logical consequence of the relative extent of exposed ground. Only ~110 km² of Heard Island is glacier-free, compared to 287 km² on Marion Island, 325 km² in Îsles Crozet and 7215 km² in Îles Kerguelen.

Sketches by sealers indicate that the ice cover on Heard Island in the 1850s to 1870s was more extensive than at any time since. The radiocarbon date of 220±113 ^{14}C yrs BP (Wk 9485) obtained from plant material beneath gravels at Long Beach indicates that some presently stable surfaces that were not glacier-covered in historical time are nevertheless young. Historical and photographic records suggest there was no significant change in glacier extent before 1929. In 1947 glaciers still covered 79% of Heard Island, but by the end of the 1980s only 70% of the island remained glacier-covered (Allison & Keage 1986, Ruddell 2001). There has been continuing subsequent recession (Ruddell 2006, Kiernan & McConnell 1999, 2002, Budd 2000). Hence, only a relatively small proportion of Heard Island has been exposed to periglacial processes prior to the past two centuries, with the well-formed vegetation-banked terraces on Mt Andree occurring in one of the longest-exposed areas. In contrast, extensive areas of Kerguelen have been deglaciated at least throughout the Holocene. The largest sorted stripes on Îles Kerguelen and rubble-covered stone-banked terraces on Marion Island are both regarded by Hall (1983a, b) as fossil and indicative of greater depth of sorting earlier in the Holocene than is occurring at present. Given unresolved questions regarding the prior extent of glaciers on Îles Kerguelen (Bellair 1965, 1969a,b, Nougier 1966, 1970, 1972, Hall 1984), it remains possible that significant parts of it remained exposed even during the Last Glacial Maximum.

Periglacial landform development on Heard Island is likely to have been further inhibited by the climatic warming that has driven land surface exposure by glacier retreat. AWS data indicate temperatures over the 1997–2000 period were ~0.6°C cooler than for 1981–82 but ~0.9°C warmer than 1948–54. From 1948–54 mean daily temperatures generally remained below 0°C from mid-June until mid-October. However, mean temperatures below 0°C now occur only between mid-July and late September, and temperatures above 0°C generally occur even on winter days. Sea surface temperatures (SST) measured at Spit Bay in winter 1992 were ~0.5–2.0°C warmer than figures recorded for the same months at Atlas Cove in 1950, although the two sampling sites were not entirely comparable (Green 2000). Mean annual SST at 52.5°S was 0.3°C cooler in 1947–54 than in 1997–2000.

Notwithstanding their limited impact on the landforms of Heard Island, periglacial processes remain significant for management of this World Heritage Wilderness Reserve. There are important interactions between periglacial processes and botanical colonisation, most conspicuously involving evolution of vegetated terraces. Any accelerated devegetation caused by human impacts would expose additional areas to periglacial erosion and there are also important ecological linkages. Thawing of the plain between Big Ben and Laurens Peninsula and the arrival of the birds that excavate breeding burrows in these sediments appeared exquisitely synchronised in November 2000, the area being re-occupied by thousands of birds within a few hours of the first summer rains and accelerated thawing. It is conceivable

that burrowing birds might exploit natural weaknesses along meltout voids. Not only can trampling collapse bird burrows, but these surfaces were sensitive to pedestrian disturbance at the onset of the melt season in late October 2000 when footprints 1 cm deep made in the morning had deepened to 4–6 cm by mid-afternoon. The fact that involutions seemed most pronounced along a route traversed daily by small parties travelling on foot suggests that the density-controlled equilibrium within some saturated sediments can be very delicate (French 2007).

Heard Island is an important location for further research into the varying periglacial environments that occur around the globe, given its position in the southern Indian Ocean south of the Antarctic Convergence. Hence, further documentation of its periglacial phenomena is warranted. Unfortunately, logistical difficulties make the detailed process studies that are the most critical requirement very difficult to achieve. However, a focus on sedimentological structures, sorting and fabrics of periglacial phenomena would allow inferences on processes to be refined (Hall 2002, Boelhouwers *et al.* 2003). Investigation of the significance of chemical weathering on Heard Island would also be very worthwhile.

CONCLUSIONS

Periglacial landforms are developed to only a limited extent on Heard Island. No evidence of thermal contraction cracking of the ground was detected. Superficial patterned ground is interpreted as having been formed by freeze-thaw cycles, but sorted polygons, terraces and stripes are only weakly developed. The absence of deep cryoturbation is attributable to the maritime climate and relatively recent exposure of most ground surfaces, in response to climatic warming that is simultaneously reducing the severity of the periglacial climate.

ACKNOWLEDGEMENTS

We are grateful to Will Powell and Paul Scott for company and assistance in the field, to Doug Thost for assistance in obtaining climate data, and to Ellen Kiernan for assistance with the morphometric analyses. Peter McIntosh, Damian Gore, Jon Stephenson and Pat Quilty provided helpful comments on a draft manuscript. The research was made possible by an Australian Antarctic Science Grant.

REFERENCES

Allison, I. & Keage, P. 1986: Recent changes in the glaciers of Heard Island. *Polar Record* **23**: 255–271.

Aubert de la Rue, E. 1959: Phenomenes periglaciales et actions eoliennes aux Îles Kerguelen. *Memoir Institute Scientifique de Madagascar* **E**: 1–21.

Bellair, P. 1965: Un example de glaciation aberrante, les Îles Kerguelen. *Committee Nationale Francais Recherches Antarctiques* **11**: 1–27.

Bellair, P. 1969a: Donnes actuelles sur les Archipels des Crozet et des Kerguelen. *In* Van Zinderen Bakker, E.M. (ed.): *Palaeoecology of Africa and of the Surrounding Islands and Antarctic.* Balkema, Cape Town: 165–174.

Bellair, P. 1969b: Soil stripes and polygonal ground in the sub-Antarctic islands of Crozet and Kerguelen. *In* Pewe, T.L. (ed.): *The Periglacial Environment, Past and Present.* McGill-Queen's University Press, Montreal: 217–222.

Bergstrom, D. & Selkirk, P.M. 2000: Terrestrial vegetation and environments on Heard Island. *In* Banks, M.R. & Brown, M.J. (eds): *Heard Island Papers. Papers and Proceedings of the Royal Society of Tasmania* **133**(2): 33–46.

Boelhouwers, J., Holness, S. & Sumner, P. 2003: The maritime Subantarctic: a distinct periglacial environment. *Geomorphology* **52**: 39–55.

Budd, G.M. 2000: Changes in Heard Island glaciers, king penguins and fur seals since 1947. *In* Banks, M.R. & Brown, M.J. (eds): *Heard Island Papers. Papers and Proceedings of the Royal Society of Tasmania* **133**(2) 47–60.

Colhoun, E.A. & Peterson, J.A. 1986: Quaternary landscape evolution and the cryosphere: research progress from Sahul to Australian Antarctica. *Australian Geographical Studies* **24**: 145–167.

Corty, M.A., Goldberg, P. & Macphail, R. 1989: *Soils and Micromorphology in Archaeology.* Cambridge University Press, Cambridge: 206 pp.

French, H.M. 2007: *The Periglacial Environment.* 3rd ed. Wiley, Chichester: 458 pp.

Green, K. 2000: Coastal studies at Heard Island 1992/93: Changes in sea surface temperature and coastal landforms. *In* Banks, M.R. & Brown, M.J. (eds): *Heard Island Papers. Papers and Proceedings of the Royal Society of Tasmania.* **133**(2): 27–32.

Hall, K. 1979a: Sorted stripes orientated by wind action: some observations from sub-Antarctic Marion Island. *Earth Surface Processes* **4**: 281–289.

Hall, K. 1979b: Late glacial ice cover and palaeotemperatures on sub-Antarctic Marion Island. *Palaeogeography, Palaeoclimatology, Palaeoecology* **29**: 243–259.

Hall, K. 1981: Observations on the stone-banked lobes of Marion Island. *South African Journal of Science* **77**: 129–131.

Hall, K. 1983a: Sorted stripes on sub-Antarctic Kerguelen Island. *Earth Surface Processes and Landforms* **7**: 45–51.

Hall, K. 1983b: Observations of some periglacial features and their palaeoenvironmental implications on sub-Antarctic islands Marion and Kerguelen. *South African Journal of Antarctic Research* **13**: 35–40.

Hall, K. 1984: Evidence in favour of an extensive ice cover on sub-Antarctic Kerguelen Island during the last glacial. *Palaeogeography, Palaeoclimatology, Palaeoecology* **47**: 225–232.

Hall, K. 2002: Review of present and Quaternary periglacial processes and landforms of the maritime and sub-Antarctic region. *South African Journal of Science* **98**: 71–81

Harland, W.B. 1957: Exfoliation joints and ice action. *Journal of Glaciology* **3**: 21, 8–10.

Jacka, T.H. & Ruddell, A. 1998: Construction of a temperature record for Heard Island, and comparison with glacier fluctuations. *American Geophysical Union Fall Meeting, San Francisco, California, USA, supplement to EOS, Transactions: F55 (Abstracts U31E-04):* 32.

Kiernan, K. & McConnell, A. 1999: Geomorphology of the Sub-Antarctic Australian Territory of Heard Island-McDonald Island. *Australian Geographer* **30**: 159–195.

Kiernan, K. & McConnell, A. 2002: Glacier retreat and melt-lake expansion at Stephenson Glacier, Heard Island World Heritage Area. *Polar Record* **38**(207): 297–308.

Kuenen, P.H. 1956: Experimental abrasion of pebbles. 2. Rolling by current. *Journal of Geology* **64**: 336–338.

Lambeth, A.J. 1950: Heard Island: geography and glaciology. *Royal Society of New South Wales Journal and Proceedings* **86**: 92–98.

McGreevy, J.P. & Whalley, W.B. 1982: The geomorphic significance of rock temperature variations in cold environments: a discussion. *Arctic and Alpine Research* **14**: 157–162.

Markov, K.K. 1971: Kerguelen Islands. *Antarctica Commission Reports* **1968**: 43–58.

Nougier, J. 1964: Observations periglaciaires dans l'Archipel de Kerguelen, Terres Australes et Antarctiques Francaises. *Zeitschrift fur Geomorphologie* **8**: 143–149.

Nougier, J. 1966: Lacs frontaux des glaciers de l'archipel de Kerguelen. *Revue of Geographie Physical and Geology Dynamique* **8**(2): 161–169.

Nougier, J. 1970: Contribution a l'etude geologigique et geomorphologique de IÎes Kerguelen, *Committee Nationale Francais. Recherches Atarctiques* **27**(2): 379–381.

Nougier, J. 1972: Aspects de mopho-tectonique glaciaire aux Îles Kerguelen. *Revue of Geographie Physical and Geology Dynamique* **14**(5): 499–505.

Pendlebury, S.F. & Barnes-Keoghan, I.P. 2007: Climate and climate change in the sub-Antarctic. *In* Selkirk, P.M. Quilty, P.G. & Davies, M. (eds): *The Sub-Antarctic. Papers and Proceedings of the Royal Society of Tasmania* **141**(1): 67–82.

Pihlainen, J.A. & Johnston, G.H. 1963: *Guide to a Field Description of Permafrost.* National Research Council of Canada, Associate Committee on Snow & Soil Mechanics, Technical Memorandum 79 (National Research Council Publication 7576): 262 pp.

Ruddell, A. 2001: Our subantarctic glaciers: Why are they retreating? *Australian Antarctic Magazine* **2**: 33–34.

Ruddell, A. 2006: An inventory of present glaciers on Heard Island and their historical variation. *In* Green, K. & Woehler, E. (eds): *Heard Island: Southern Ocean Sentinel.* Surrey Beatty & Sons, Chipping Norton: 28–51.

Selkirk, J. M. 1998: Active vegetation-banked terraces on Macquarie Island. *Zeitschrift fur Geomorphologie* **42**: 483–496.

Sneed, E.D. & Folk, R.L. 1958: Pebbles in the Colorado River, Texas: A study in particle morphogenesis. *Journal of Geology* **66**: 114–179.

Stephenson, J., Barling, J., Wheller, G. & Clarke, I. 2006: The geology and volcanic geomorphology of Heard Island. *In* Green, K. & Woehler, E. (eds): *Heard Island: Southern Ocean Sentinel.* Surrey Beatty & Sons, Chipping Norton: 10–27.

Sugden, W. 1968: Ventifacts. *In* Fairbridge, R.W (ed.): *The Encyclopedia of Geomorphology.* Dowden, Hutchinson & Ross, Stroudesburg, Pennsvlvania, USA: 1192–1193.

Thost, D. & Allison, I. 2006: The climate of Heard Island. *In* Green, K. & Woehler, E. (eds): *Heard Island: Southern Ocean Sentinel.* Surrey Beatty & Sons, Chipping Norton: 52–68

Troll, C. 1960: The relationship between the climates, ecology and plant geography of the southern cold temperature zone and of the tropical high mountains. *Proceedings of the Royal Society of London* B **152**: 529–532.

Truswell, E.M., Quilty, P.G., McMinn, A., Macphail, M.K. & Wheller, G. 2005: Late Miocene vegetation and palaeoenvironments of the Drygalski Formation, Heard Island, Indian Ocean: evidence from palynology. *Antarctic Science* **17**: 427–442.

Whalley, W.B., Douglas, D.R. & McGreevy, J.P. 1982: Crack propogation and associated weathering in igneous rocks. *Zeitschrift fur Geomorphologie* **26**: 33–54.

(accepted 26 February 2008)

THE DIET OF THE TASMANIAN DEVIL, *SARCOPHILUS HARRISII*, AS DETERMINED FROM ANALYSIS OF SCAT AND STOMACH CONTENTS

by David Pemberton, Sam Gales, Belinda Bauer, Rosemary Gales, Billie Lazenby and Kathryn Medlock

(with two text-figures, one plate and five tables)

Pemberton, D., Gales, S., Bauer, B., Gales, R., Lazenby, B. & Medlock, K. 2008 (28:xi): The diet of the Tasmanian Devil, *Sarcophilus harrisii*, as determined from analysis of scat and stomach contents. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 13–22. ISSN 0080-4703. Department of Primary Industries and Water, GPO Box 44, Hobart, Tasmania 7001, Australia (DP*, RG, BL); Friends School, PO Box 42, North Hobart, Tasmania 7002, Australia (SG); Tasmanian Museum and Art Gallery, GPO Box 1164, Hobart, Tasmania 7001, Australia (BB, KM). * Author for correspondence. Email: David.Pemberton@dpiw.tas.gov.au

Knowledge of the diets of carnivores is an essential precursor to understanding their role as predators in ecosystems. To date, understanding of the diet of Tasmanian Devils, *Sarcophilus harrisii*, is limited and based upon largely qualitative descriptions. We examined the diets of Tasmanian Devils at six sites by identifying undigested hair, bone and feathers found in their scats. These sites range across different habitat types in coastal and inland Tasmania, and encompass devil populations that are known as both free of the Devil Facial Tumour Disease (DFTD) and populations that are infected by the disease. Tasmanian Devil scats at coastal sites (n=27) contained ten species of mammal, as well as birds, fish and insects. Scats collected from inland sites (n=17) were comprised of six mammalian species, birds and invertebrates. The most common food items were birds, Common Brushtail and Ringtail possums (*Trichosurus vulpecula* and *Pseudocheirus peregrinus* respectively), Tasmanian Pademelons (*Thylogale billardierii*) and Bennett's Wallabies (*Macropus rufogriseus*). Of all the scats, 61% contained only one food group, 32% contained two groups, 4% contained three food items and only one scat (2%) contained four food groups. We supplement this information with stomach contents from road-killed devils, and compare our results with those of previous studies, with a view to furthering our understanding of the ecology of the threatened Tasmanian Devil. Such information will be important for the management of wild and captive devil populations, particularly in light of DFTD.

Key Words: Tasmanian Devil, *Sarcophilus harrisii*, diet, Common Ringtail Possum, *Pseudocheirus peregrinus*, Tasmanian Pademelon, *Thylogale billardierii*, Bennett's Wallaby, *Macropus rufogriseus*.

INTRODUCTION

The Tasmanian Devil, *Sarcophilus harrisii* (Owen, 1838), is the largest extant carnivorous marsupial and is unique to Tasmania. The conservation status of this endemic species has recently become endangered by an infectious disease, known as Devil Facial Tumour Disease (DFTD). The disease is a cancer that kills up to 80% of individuals in affected populations. No individual has been known to survive the disease, which has spread across over 50% of the species range (Hawkins *et al.* 2006).

Management options for the Tasmanian Devil include captive breeding programs, isolating wild populations on Tasmanian offshore islands, and isolating free-ranging populations on mainland Australia or in Tasmanian reserves. Effective management of both wild and captive populations requires a comprehensive understanding of the food requirements of the species. Surprisingly, this aspect of the biology of Tasmanian Devils is poorly understood, as to date there have been few quantitative studies of their diet.

Weighing up to 13 kg, the Tasmanian Devil is significantly larger than other carnivorous marsupials. Previous studies of the diet of the Tasmanian Devil report that the species is largely carnivorous with a variety of prey species being consumed. Fleay (1952) documented anecdotal information on the diet of the species. Güiler (1970) analysed the diet of Tasmanian Devils at Cape Portland (northeast Tasmania) and Granville Harbour (western Tasmania) based on scats and stomach contents and Green (1967) examined the stomach contents of 30 Tasmanian Devils from northeast Tasmania. An assessment of the diet of the Tasmanian Devil at Cradle Mountain was reported by Jones & Barmuta (1998) although this study characterised the diet in categories of prey body mass rather than by species composition. Taylor (1986) examined 28 Tasmanian Devil scats collected from the upper Henty River region of western Tasmania, and prior to the present study, this was the only quantitative study that reported on species identification of prey remains based on sectioning and microscopic identification of fur according to the standard technique of Brunner & Coman (1974).

By adopting a quantitative approach, the present study aims to identify the prey consumed by Tasmanian Devils at six sites. These include three coastal sites in western Tasmania (Temma, Discovery Beach and Sandy Cape), and three inland sites, (Togari, Fentonbury and Bronte) (fig. 1). These sites comprise a range of habitat types, as well as populations that are known to be either free of DFTD, or infected by the disease. Here, we describe the diets of devils at this range of sites, and conduct a meta-analysis of this and previous dietary studies of the species. Our results will not only further our understanding of the ecology of this threatened species, but also provide information important for the management of wild and captive populations.

MATERIAL AND METHODS

Diet Determination

The diet composition was determined by identifying prey remains in the scats of devils. In this study, a scat was defined as a single formed stool. Scats were collected from trapped devils at all sites except Sandy Cape where they were collected from latrines. Tasmanian Devils typically deposit faeces at regularly used latrines, and depending on population size,

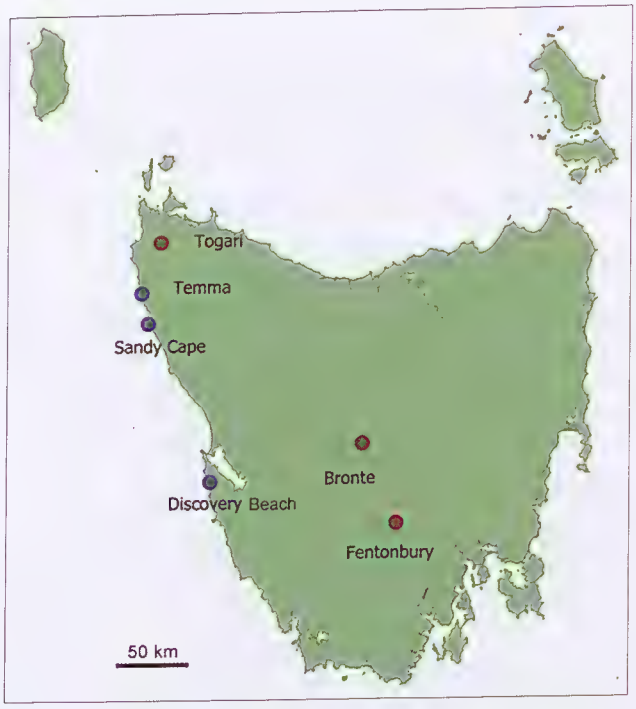


FIG. 1 — Locations where Tasmanian Devil scats were collected for analysis in this study (red indicates inland sites, and blue indicates coastal sites).

numerous devils may use one latrine. These are often near a creek crossing or other water source (Owen & Pemberton 2005). Tasmanian Devil scats can be differentiated from other carnivore scats by their larger size and shape, being tightly twisted and cylindrical (Triggs 1996). Only fresh scats were collected. The stomach contents of nine Tasmanian Devils that were accidentally killed on roads were also examined to compare the results from scat and stomach contents.

Sampling sites and times

Tasmanian Devil scats were collected from three coastal and three inland sites between October 2006 and April 2007 (fig. 1, table 1). Scats were collected as a part of the current study or were contributed to the study from collections undertaken by the Tasmanian Museum and Art Gallery (TMAG) or Department of Primary Industries and Water (DPIW).

Coastal sites

Temma is located south of the Arthur River and north of the Sandy Cape study site on the west coast of Tasmania. There is one gravel road into the area which is frequented by shack owners, fishers and recreational users. The coast is characterised by sandy bays and rocky headlands with Marram Grass, *Ammophila arenaria* L., covered dunes and coastal scrub bounding on wet marshes and tea tree scrub. Cattle are grazed seasonally on the coastal strip and tree farms (predominantly *Eucalyptus nitens* Maiden) are currently being developed in the area.

Sandy Cape is south of Temma on the edge of and included in the Tarkine National Park. The area is similar to Temma and includes areas of grazed land. The Sandy Cape area is dominated by sand dunes. The stable dunes are vegetated with coastal scrub and heathland. Common Wombat, *Vombatus ursinus* (Shaw, 1800), burrows are common in the dunes.

Discovery Beach is located south of Macquarie Harbour on the west coast. It is visited by few and supports a rich fauna including significant numbers of Tasmanian Devils. The coastal scrub is bounded by tea tree forest (*Leptospermum* spp.), eucalypt woodland (*Eucalyptus* spp. and buttongrass moorland (*Gymnoschoenus sphareocephalus* (R.Br.) Hook.f.). The dense tea tree forests make for ideal denning habitat for devils (N. Mooney pers. comm.).

TABLE 1
Details of the location and dates of the scat collections analysed in the study

	Location	Number of scats collected	Month scats collected
Coastal sites			
Temma	41°13'58"S; 144°41'38"E	2	March 2007
Sandy Cape	41°25'0"S; 144°45'00"E	18	October 2006
Discovery Beach	42°23'25"S; 145°14'00"E	7	March 2006
Total coastal scats		27	
Inland Sites			
Togari	40°55'34"S; 144°54'24"E	8	March 2007
Bronte	42°05'24"S; 146°23'40"E	5	April 2007
Fentonbury	42°36'45"S; 146°46'00"E	4	April 2007
Total inland scats		17	
Total scats		44	

Inland sites

Togari is in the northwest of Tasmania, located 50 km west of Smithton. The habitat is dominated by wet sclerophyll forests and Blackwood, *Acacia melanoxylon* R.Br, and tea tree swamps. There is extensive logging and associated vehicle use of the area.

Bronte is located on the edge of the Central Plateau, and the habitat is dominated by eucalypt forests, buttongrass plains and grassland valleys. The area is extensively logged and grazed. There is widespread shooting of wallabies and possums in the area. DFTD is prevalent in the devil population in this area.

Fentonbury is a rural landscape comprised of dry sclerophyll forests and improved pastures. DFTD is prevalent in the devil population in this area.

Stomach analysis

Carcasses of nine Tasmanian Devils that had been accidentally killed on Tasmania's roads were provided by the TMAG for analysis. The carcasses were thawed and dissected to remove their stomachs. Using forceps and scalpels, the stomachs were cut open, contents removed then brushed with a wet 4 mm paint brush to remove all contents adhering to the stomach walls. Contents were washed in hot water over a sieve to collect all remains and then air dried and stored in individually labelled zip-lock plastic bags. Later, the remains were sorted into categories including hair, bones, skin, nails and claws and unidentified objects. Sorted remains were then documented and re-bagged.

Scat analysis

Scats from trapped Tasmanian Devils were provided by the DPIW for analysis. Scats were soaked in *Virkon*, a broad spectrum disinfectant used for effective control of viruses, bacteria and fungi, for a minimum of six hours to reduce the risk of zoonoses. Scats were then palpated with tweezers to soften them and sieved with hot water to collect diagnostic prey remains. Remains were left to air dry before being stored in labelled plastic bags. Categories for sorting included hair, bones, feathers, nails, claws, skin and unidentified objects.

Analysis of prey remains

Hairs were examined under a binocular compound light microscope and identified using the Hair ID software (Brunner & Triggs 2002), which characterises hair attributes for different species such as shape of hair in cross section, size/shape of the medulla, and colour. TMAG voucher specimens were also used to confirm identification of hair and other diagnosed remains including feathers, bones and claws.

In documenting prey remains it was assumed that the remains of a species in a scat were derived from a single individual unless there was definitive evidence for more than one individual. An occurrence is therefore defined as the presence of a prey item in a scat. In the case of birds, not all remains could be identified to species level and hence the group is treated as one prey item when describing abundance data. Where bird species were identified, they are described separately. The diet composition was assessed in two ways – composition by number of individuals, and frequency of occurrence – as each method has its own form of bias (Hyslop 1980). Composition by number was calculated from the number of occurrences of each prey item divided by the total number of occurrences of all prey items, expressed as a percentage to give the actual proportions of prey items. Frequency of occurrence of prey items is expressed as the number of occurrences of each prey item divided by the total number of scats, expressed as a percentage.

RESULTS

A total of 44 Tasmanian Devil scats that had been collected from six different sites were analysed (table 1, fig. 1). Tasmanian Devils were found to consume mammals, birds, fish, insects and plant material (table 2). The most important prey groups were mammals and birds. Over 60% of the prey items identified were mammal, most of which (56.7%) were native species. Eight species of native mammals were identified in the diet. The three species that contributed most significantly to the diet, both in terms of prey composition and frequency of occurrence, were Common Ringtail Possums, *Pseudocheirus peregrinus* (Boddaert, 1785), followed by Pademelons, *Thylogale billardierii* (Desmarest, 1822), and Bennett's Wallaby, *Macropus rufogriseus* (Desmarest, 1817). Domestic or introduced mammal species occurred relatively infrequently (9.1%), contributing 6.0% of the prey items identified.

Birds were represented by bones and feathers and two species could be confidently identified as Little Penguins, *Eudyptula minor* (J.R. Forster, 1781) and Short-tailed Shearwaters, *Puffinus tenuirostris* (Temminck, 1835). A large species of gull was represented, but the species identification could not be distinguished between either Pacific, *Larus pacificus* Latham, 1802, or Kelp gull, *Larus dominicus*, M.H.K. Litchenstein, 1823. The remaining bird items were all small, dark brown body feathers and probably represented one species, but could not be definitively identified. As a result of this uncertainty, birds are considered as one prey group for this study.

Invertebrates were found in two scats and fish remains in another. The invertebrates found were the remains of carnivorous beetles that are associated with rotting carcasses and maggots associated with kelp in one scat.

To compare the prey items present in scats in relation to location the data were compared between coastal (Sandy Cape, Discovery Beach and Temma) and inland (Togari, Fentonbury and Bronte) sites (tables 2, 3 and 4). The small sample size restricts the conclusions that can be made relative to diversity of the diet (Glen & Dickman 2008). The food items however, clearly represent coastal-derived material which would not be found inland. For this reason a comparison is made between the two data sets in the absence of greater sample size to support an analysis of diversity of food items. This comparison shows that Tasmanian Devils at coastal sites consumed seabirds, seals and in addition scavenged on whales (pl. 1). In comparison, scats collected from inland sites comprised mammals and birds. The principal prey species of Tasmanian Devils at coastal sites, in order of both composition and frequency of occurrence, were birds (Short-tailed Shearwaters, Little Penguins and gulls), Common Ringtail Possums and Pademelons. In comparison, the principal prey species represented in the scats of Tasmanian Devils at inland sites were Bennett's Wallaby and birds, followed by Pademelons and Common Brushtail Possums in equal representation.

TABLE 2
Food items in 44 Tasmanian Devil scats from coastal and inland sites in Tasmania

		Coastal	Inland	Total (*n*)[1]	Composition[2] (%)	Frequency[3] (%)
Number of scats		27	17	44		
Native mammal						
Ornithorynchus anatinus	Platypus	2	0	2	3.0	4.5
Tachyglossus aculeatus	Echidna	1	1	2	3.0	4.5
Vombatus ursinus	Common Wombat	2	0	2	3.0	4.5
Pseudocheirus peregrinus	Common Ringtail Possum	8	1	9	13.4	20.4
Trichosurus vulpecula	Brushtail Possum	1	3	4	6.0	9.1
Thylogale billardierii	Pademelon	5	3	8	11.9	18.1
Macropus rufogriseaus	Bennett's Wallaby	0	8	8	11.9	18.1
Arctocephalus sp.	Fur seal	3	0	3	4.5	6.8
Total native mammal		22	16	38	56.7	86.4
Introduced/domestic mammal						
Oryctolagus cuniculus	Rabbit	1	0	1	1.5	2.3
Bos taurus	Cattle	1	1	2	3.0	4.5
Rattus norvegicus	Norway Rat	1	0	1	1.5	2.3
Total non native mammal		3	1	4	6.0	9.1
Bird		17	5	22	32.8	50.0
Fish		1	0	1	1.5	2.3
Insects		1	1	2	3.0	4.5
Total occurrence		44	23	67		

[1] (*n*) is occurrence.
[2] Composition is the number of occurrences of a prey item divided by the total number of occurrences of all items.
[3] Frequency is the number of occurrences divided by the total number of scats.

TABLE 3
Food items in 27 Tasmanian Devil scats collected from coastal sites in Tasmania: Sandy Cape, Discovery Beach and Temma

		Sandy Cape (*n*)[1]	Discovery Beach (*n*)	Temma (*n*)	n	Composition[2] (%)	Frequency[3] (%)
Mammal							
Ornithorynchus anatinus	Platypus	0	1	1	2	4.5	7.4
Tachyglossus aculeatus	Echidna	0	1	0	1	2.3	3.4
Vombatus ursinus	Common Wombat	2	0	0	2	4.5	7.4
Pseudocheirus peregrinus	Common Ringtail Possum	6	2	0	8	18.2	29.6
Trichosurus vulpecula	Brushtail Possum	0	0	1	1	2.3	3.4
Thylogale billardierii	Pademelon	5	0	0	5	11.4	18.5
Arctocephalus sp.	Fur Seal	2	1	0	3	6.8	11.1
Rattus norvegicus	Norway Rat	1	0	0	1	2.3	3.4
Oryctolagus cuniculus	Rabbit	1	0	0	1	2.3	3.4
Bos taurus	Cattle	0	0	1	1	2.3	3.4
Total mammal		17	5	3	25	56.8	92.6
Bird		10	6	1	17	38.6	63
Fish		1	0	0	1	2.3	3.7
Kelp and maggots		0	1		1	2.3	3.7
Total		28	12	4	44		

[1] (*n*) is occurrence.
[2] Composition is the number of occurrences of a prey item divided by the total number of occurrences of all items.
[3] Frequency is the number of occurrences divided by the total number of scats.

TABLE 4
Food items in 17 Tasmanian Devil scats from inland Tasmanian sites: Togari, Fentonbury and Bronte

		Fentonbury (*n*)[1]	Togari (*n*)	Bronte (*n*)	*n*	Composition[2] (%)	Frequency[3] (%)
Mammal							
Tachyglossus aculeatus	Echidna	0	0	1	1	4.4	5.9
Pseudocheirus peregrinus	Common Ringtail Possum	0	1	0	1	4.4	5.9
Trichosurus vulpecula	Brushtail Possum	2	1	0	3	13.0	17.5
Thylogale billardierii	Pademelon	1	2	0	3	13.0	17.7
Macropus rufogriseus	Bennett's Wallaby	1	3	4	8	34.8	47.1
Bos taurus	Cattle	0	1	0	1	4.4	5.9
Total mammal		4	8	5	17	73.9	100
Bird		1	2	2	5	21.7	29.4
Invertebrate		0	1	0	1	4.4	5.9
Total		5	11	7	23		

[1] (*n*) is occurrence.
[2] Composition is the number of occurrences of a prey item divided by the total number of occurrences of all items.
[3] Frequency is the number of occurrences divided by the total number of scats.

PLATE 1
Tasmanian Devil scavenging on a long-finned pilot whale, Globicephala melas *Traill, 1809, near Discovery Beach on the west coast of Tasmania. Photo by Jon Marsden-Smedley.*

Of all the scats, 61% contained only one prey group, 32% contained two prey groups, 4% contained three prey items and only one scat (2%) contained four prey groups (fig. 2).

All five prey taxa that were identified from the nine Tasmanian Devil stomachs were also represented in the scat analyses. In the stomachs, Common Brushtail Possum occurred most frequently (n = 4, 57%), followed by Bennett's Wallaby (n = 2, 28%), birds (n = 2, 28%), Pademelon (n = 1, 14%) and rabbits, *Oryctolagus cuniculus* (Linnaeus, 1758) (n = 1, 14%).

DISCUSSION

Prior to the present study, the only other investigation of Tasmanian Devil diet that used diagnostic microscopic examination of hair to report upon identification of prey species was that of Taylor (1986), who analysed the hairs collected from 28 scats from one site, the upper Henty River. More recently Jones & Barmuta (1998) used hair analysis to characterise the prey species of Tasmanian Devils from analyses of scats, but their results do not provide information on species identifications, rather prey categories: large mammal, small mammal etc. The present study therefore presents a significant advance in our understanding of the diet of Tasmanian Devils.

Whilst microscopic examination of hair is a robust technique, it is important to note that there are limitations to the analyses of diet based on identification of stomach and scat contents. These limitations include lack of information on the size or age of the prey consumed, and some prey taxa, for example earthworms, may be missed completely due to their greater digestibility (Corbett 1989). With regard to differing rates in digestibility, the present study found that prey species/groups that were observed in stomach contents were also detected in scat analyses. Further comparisons between stomach and scat contents from different regions and age classes of devils would strengthen this argument. In light of relatively small sample sizes, and the lack of biomass data for estimating original prey sizes in Tasmania, the present study did not attempt to assign importance to prey items. The small sample size is largely the result of the difficulty of attaining verified devil scats. This is currently been addressed through the collection of samples from the devil monitoring program conducted by DPIW.

Comparison with other studies

Our results support previous reports that the Tasmanian Devil consumes a wide variety of prey, and is predominantly a carnivore (table 5). This is similar to the Spotted-tailed Quoll, *Dasyurus maculatus* (Kerr, 1792) (Belcher 1995, Jarman *et al.* 2007), but different from the other Tasmanian carnivorous marsupial, the smaller Eastern Quoll, *Dasyurus viverrinus* (Shaw, 1800), whose diet includes a large proportion of insects (Blackhall 1980, Jones & Barmuta 1998).

A comparison across all the studies that report on the prey species of the Tasmanian Devil clearly shows that of the 29 food types identified, mammals are the most frequently consumed taxon (table 5). Within this group, 23 species are represented, including monotremes, marsupials, placental mammals and marine mammals (pl. 1). A compelling result reported by Guiler (1970) is that Tasmanian Devils have a wide food spectrum, and consume introduced as well as native species, but that in each area, their food was dominated by approximately three species. This result is also reflected in the comparison between studies reported here (table 5) and this also shows that the significant prey species vary between studies. Across the studies however, the most frequently reported prey species for Tasmanian Devils are Bennett's Wallaby and Common Ringtail Possums (four and five studies respectively), Pademelon (three studies) and sheep, *Ovis aries* Linnaeus, 1758, (two studies). In the present study, birds were also uniquely reported as a significant prey group. Other studies have reported that birds are of minor importance to the diet of the Tasmanian Devil (table 5). The observation that Bennett's Wallabies were one of the most commonly encountered food items in inland scats is supported by a study which found that areas with higher devil densities tend to be associated with areas where there are high spotlight counts of Bennett's Wallabies (Marvanek 2006).

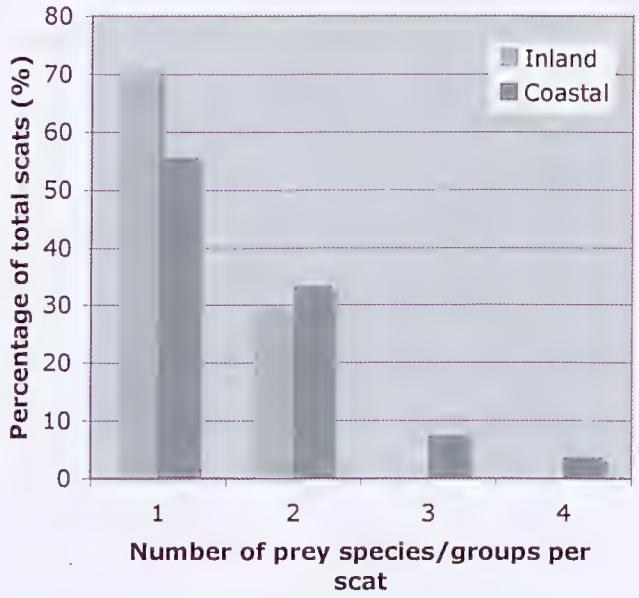


FIG. 2 — Comparison of the number of prey species/groups occurring in Tasmanian Devils scats collected at coastal and inland sites.

Overall, the present study identified 15 food groups for the Tasmanian Devil (table 5), a diversity surpassed only by Guiler (1970) who reported a broader range of prey items (21 groups), including vegetation, insects, amphibians, Urochordata and reptiles. However, the records of Guiler (1970) included many anecdotal records and were collected over an unspecified time period. Further, whilst Guiler states whether they were made from scats or stomach contents, there is no description of how the identification was determined. The relatively high diversity reported in the present study likely results from the use of hair analysis, which provide a more robust and quantitative assessment of dietary remains than macroscopic visual assessments, as well as analysing scats that were collected from a variety of sites. Taylor (1986) also used hair analysis, but, compared to the present study, was reporting on fewer scats (28) from a single location. Jones & Barmuta (1998) also undertook hair analysis but did not provide details of species composition, so cannot be considered in this comparison, except for the major prey species that were specified.

The comparison of dietary items in coastal and inland scats in the present study showed that regional differences in diet do occur with coastal diet including food items

TABLE 5
Food items reported in the diet of the Tasmanian Devil in published accounts

		This study	Jones & Barmuta (1998)	Marshall & Cosgrove (1990)	Taylor (1986)	Guiler (1970)	Green (1967)	Fleay (1952)
Native mammal								
Ornithorynchus anatinus	Platypus	•[1]						
Tachyglossus aculeatus	Echidna	•				•		
Dasyurus sp	Quoll species					•		
Sarcophilus harrisii	Tasmanian Devil					•	•	
Antechinus sp.	Antechinus species				•••			
Isoodon obesulus	Brown Bandicoot					•		
Perameles gunnii	Eastern Barred Bandicoot					•		
Vombatus ursinus	Common Wombat	•	•••	•		•••		•••
Pseudocheirus peregrinus	Common Ringtail Possum	•••[2]		•••	•••	•••		
Trichosurus vulpecula	Brushtail Possum	•				•	•	
Cercartetus nanus	Eastern Pygmy Possum							
Thylogale billardierii	Pademelon	•••		•••	•••	•		
Macropus rufogriseus	Bennett's wallaby	•••	•••			•••	•••	•••
Rattus lutreolus	Swamp Rat				•	•		
Pseudomys higginsi	Long-tailed Mouse				•			
Arctocephalus sp.	Fur seal	•						
Introduced/domestic								
Ovis aries	Sheep					•••	•••	
Oryctolagus cuniculus	Rabbit	•				•		
Bos taurus	Cattle	•				•		
Canis lupus familiaris	Dog					•		
Felis catus	Cat					•		
Equus caballus	Horse					•		
Rattus rattus	Black Rat	•						
Bird		•••	•		•	•	•	•
Fish		•						
Amphibian								
Reptile						•		•
Insects		•	•		•	•		•

[1] Less frequent and incidental species. [2] Frequently occurring prey species.

common to the region such as seabirds, seals and whales, whereas the scats from the inland sites most commonly revealed Bennett's Wallaby and to a lesser extent birds, Pademelons and Common Brushtail Possums. These results clearly indicate and reflect differences in locations with associated differences in land use and available prey. The inland sites in the present study encompass a more rural and pastoral landscape, where in some areas there is extensive control of wallabies and Common Brushtail Possums. In comparison, the coastal locations reflect more remote and less modified environments. The Discovery Beach area is coastal heathland and wet forest, whilst the Sandy Cape site consists of coastal dunes and scrub which is grazed for only six weeks of the year. Previously Green (1967) has reported that Tasmanian Devils in some areas have benefited from the existence of the pastoral industry because of the large availability of food from this source. Studies of the diet of devils in pastoral areas (Green 1967, Guiler 1970) show that domestic stock (e.g., sheep) or native animals that have been killed on the roads or as agricultural pests (Bennett's Wallaby) have been significant food items. These results are consistent with the present study.

Another detailed study of the prey remains of Tasmanian Devils, was a study of the characteristics of bones in devil scats by Marshall & Cosgrove (1990) which was conducted on a collection of scats from the central highlands of Tasmania. The study was not designed to examine the diet of the Tasmanian Devil but the dominant prey items were identified and clearly showed that Common Ringtail Possums and Pademelons were significant in the diet of Tasmanian Devils at this site. Similarly, Common Ringtail Possums and Pademelons were dominant prey species in the diet of Tasmanian Devils in the sub-alpine wet forests of the upper Henty River (Taylor 1986).

Foraging ecology as deduced from diet

The sizes of mammals whose remains were detected in scats in this and other studies ranged from mice to cattle and fur seals, with the majority coming from macropods and possums (table 5). The Tasmanian Devil therefore is not narrowly specialised in the mammals it consumes, but feeds upon both large and small species, that may be terrestrial, aquatic or arboreal. Some of the mammal species reported

as being eaten, such as fur seals, were probably too large for the devils to have killed, their consumption likely resulting from the devils scavenging on carcasses. Scavenging on large carcasses is a behaviour common to the Tasmanian Devil (Pemberton & Renouf 1994).

Earlier studies have reported that Tasmanian Devils are inept killers that scavenge rather than hunt (Buchmann & Guiler 1977, Guiler 1970). Nonetheless, Guiler (1970) reported circumstantial evidence that devils may kill weak and debilitated lambs. The presence of fur seals in the diet in the present study suggests that the Tasmanian Devils were scavenging on beached carcasses. Dead fur seals, usually large adult males that weigh in excess of 100 kg, occasionally wash ashore on the Tasmanian coastline (Terauds *et al.* in press). A food resource such as this could last for weeks before it was too decomposed to be consumed by devils and therefore can be a rich patch of accessible food. In pastoral areas, road kills and crop protection control programs also make Bennett's Wallaby, Pademelons and Common Brushtail Possums available for scavenging by devils.

When considering the prevalence of the largely arboreal Common Ringtail Possum in the diet of the Tasmanian Devil, Taylor (1986) proposed that, rather than being an obligate scavenger, devils kill possums by climbing trees. The frequent occurrence of Common Ringtail Possums in the present study supports this suggestion that Tasmanian Devils directly hunt and actively kill this species. Young devils are capable climbers, as observed by carers of orphan devils (N. Mooney pers.comm., S. & R. Gales unpubl. data, Owen & Pemberton 2005) and also as recorded by Mrs Mary Roberts who bred devils in her zoo in the early 1900s and who remarked on their climbing ability. Roberts noted that young devils:

> *... frequently climb the wire-netting to the height of nearly six feet* and further *They were expert climbers, and although I had some specially constructed yards made, they would get up the wire-netting and walk along the top rail quite easily; at other times they would climb a pear-tree growing in their enclosure and sit in the branches like cats.* (Roberts 1915: 580–581)

She also recorded an adult Tasmanian Devil climbing a high fence.

These observations led Guiler (1970) to suggest that some predation, of birds at least, may take place up trees. This climbing ability, especially as displayed by young, or smaller, Tasmanian Devils, likely explains the significant consumption of Common Ringtail Possums, which are largely arboreal.

The high proportion of birds found in the prey of devils in the present study (50% of all scats included bird remains) may be as a result of a combination of scavenging and active predation. The birds that were most often identified in the diet of the coastal devils in this study comprised both Little Penguins and Short-tailed Shearwaters. Both these species nest in burrows in coastal dunes and would be easily accessible for predation by devils. Scavenging of beach-cast birds of these species also occurs at these sites (D. Pemberton unpubl. data, N. Mooney pers. comm.). Field observations have also been made of young devils feeding on a freshly killed quail at Cape Sorell (D. Mann, B. Bauer, pers. comm.). Therefore, the unidentified brown feathers in the coastal samples may represent a species of quail, either Brown Quail, *Coturnix ypsilophora* Bosc, 1792 or Stubble Quail, *C. pectoralis* Gould, 1837. Birds were also consumed by the inland devils with 29% of scats including bird remains. The identification of these species was not possible, but they likely include Tasmanian Native Hens, *Tribonyx mortierii* Du Bus, 1840, a large flightless water hen that flourishes on grassy paddocks.

When our results are compared and combined with those of other studies that report on the prey of Tasmanian Devils, it emerges that the feeding habits of the Tasmanian Devil include both scavenging and direct predation foraging strategies that target both mammals and birds. The prey species that are available for direct predation occur both on the ground and in trees, and vertebrate carrion is also commonly consumed.

Implications for ecological conservation and management

In the present study, the diet of Tasmanian Devils was dominated by large (Bennett's Wallaby), medium-sized (Pademelon) and small mammals (Common Ringtail Possums), as well as a significant proportion of birds. The other large mammals (wombats) that have been reported as significant prey species in the diet of Tasmanian Devils in other studies (e.g., Fleay 1952, Guiler 1970, Jones & Barmuta 1998), were largely absent in the results of the present study, occurring in less than 5% of scats.

These results have important implications for the management strategies that are being developed in response to DFTD. The clinical symptoms of DFTD, in populations that have infected individuals including Bronte and Fentonbury, are primarily detected in adults, with resistance to the disease apparently rare (Hawkins *et al.* 2006). The result of the disease, which impacts significantly on adult survival in affected populations, is that adults are rare, with most surviving individuals being young. This may well manifest in the dietary profiles of different populations.

Consequently, in populations that are affected by disease, the age of devils surviving in the population is younger than in populations that are not yet affected (e.g. the coastal sites in this study). Therefore the scats from devils at the inland sites that were dominated by Bennett's Wallaby and birds may be representing the diet of younger devils than the devils from the coastal populations on the west coast that are yet to be affected by DFTD. The prevalence of smaller prey items in the diet from inland devils as reported in this study, compared to other studies inland (Jones & Barmuta 1998), may reflect the fact that the surviving devils are now younger, and so reflect the diet preferences of younger animals (including smaller mammals and birds). Therefore, with the shifting demography of devils in affected populations, the diet will likely also change to reflect the diet preferences and foraging strategy of younger devils. Thus in more recent times, with the impact of DFTD affecting the older devils, the diet of the Tasmanian Devil may be characterised by the foraging preferences of younger animals whose prey include smaller and more arboreal species.

If the demographic age profiles in DFTD-affected populations continue to reflect mainly younger animals with few surviving adult devils, there may be implications for other mammalian predators. Jones & Barmuta (1998) report that Spotted-tailed Quolls compete for food resources (that include smaller prey) with only younger devils, as adult devils primarily depend upon large mammals. DFTD resulting in fewer surviving adult devils could therefore potentially extend the periods of competition for food resources between devils and Spotted-tailed Quolls. Balanced

against this however is the overall reduction in devil numbers as a result of population decline, thereby increasing food resources for other species, including Spotted-tailed Quolls. Therefore the net result may be an increase in the persistence of large macropod carrion and an increase in Spotted-tailed Quolls and other predators including Feral Cats, *Felis catus* Linnaeus, 1758.

Further, one of the most concerning consequences of DFTD is the enhanced potential for the establishment of Foxes, *Vulpes vulpes* (Linnaeus, 1758), in Tasmania. A commonly held view has been that the abundance of devils has prevented establishment of foxes through competition for prey and predation on denned juveniles. A reduction in devil numbers, and therefore a persistence of mammalian carrion, will provide a surplus of food, available to foxes (N. Mooney pers. comm.).

Captive management and translocation

The present study provides important information for the care of captive Tasmanian Devils. Clearly captive devils should be offered a variety of prey types, and should be held in facilities that accommodate the ability to both burrow and climb. The information from the present study will also be useful in assisting decision making when considering possible translocation sites. This study confirms that Tasmanian Devils feed on a variety of mammals and birds with a persistent consumption of Common Ringtail Possums and birds across their range. Importantly, almost 40% of scats included more than one prey item, suggesting that variety is an important element of the foraging ecology. These results suggest that choice of translocation sites must include a variety of available prey, including small mammal species such as Common Ringtail Possums. If young devils are to be caught from the wild for release in insurance sites to prevent spread of disease, then the diet and foraging strategy of the devils to be caught should be considered in light of the prey availability at the release site. The consideration of islands as translocation sites needs to accommodate these considerations. Further studies therefore need to be carried out on the seasonal and location variation in diet based on a much larger collection of scats. This is needed, particularly in response to the management actions resulting in the translocation of Tasmanian devils from and to dramatically different habitats.

ACKNOWLEDGEMENTS

We acknowledge the support of Brian Looker and Nick Mooney with fieldwork, discussions and encouragement. TMAG and DPIW provided samples and logistical support to the project. Thanks to rangers Chris Arthur and Lalani Hyett who assisted with field activities, particularly with their local knowledge.

REFERENCES

Belcher, C.A. 1995: Diet of the Tiger Quoll (*Dasyurus maculatus*) in East Gippsland, Victoria. *Wildlife Research* **22**: 341–357.

Blackhall, S. 1980: Diet of the eastern native cat, *Dasyurus viverrinus* (Shaw) in southern Tasmania. *Australian Widlife Research* **7**: 191–197.

Brunner, H. & Coman, B.J. 1974: *The Identification of Mammalian Hair.* Inkata Press, Melbourne, Australia: 176 pp.

Brunner, H. & Triggs, B. 2002: *Hair ID: An interactive tool for identifying Australian mammal hair.* CSIRO Publishing, Melbourne, Victoria: CD ROM.

Buchmannn, O.L.K. & Guiler, E.R. 1977: Behaviour and ecology of the Tasmanian Devil, *Sarcophilus harrisii. In* Stonehouse, B. & Gilmore, D. (eds): *The Biology of Marsupials.* Macmillan, London: 155–168.

Corbett L.K. 1989. Assessing the diet of dingoes from faeces: a comparison of 3 methods. *Journal of Wildlife Management* **53**: 343–346.

Fleay, D. 1952: The Tasmanian or marsupial devil – its habits and family life. *Australian Museum Magazine* **10**: 275–280.

Glen, A.S. & Dickman, C.R. 2008: Niche overlap between marsupial and eutherian carnivores: does competition threaten the endangered Spotted-tailed Quoll? *Journal of Applied Ecology* **45**: 1–8.

Green, R.H. 1967: Notes on the Devil (*Sarcophilus harrisii*) and the Quoll (*Dasyurus viverrinus*) in North-eastern Tasmania, *Records of the Queen Victoria Museum* **27**: 2–13.

Guiler, E. 1970: Observations on the Tasmanian Devil, *Sarcophilus harrisii* (Marsupialia: Dasyuridae) 1. Numbers, home range, movements and food in two populations. *Australian Journal of Zoology* **18**: 49–62.

Hawkins, C.E., Baars, C., Hesterman, H., Hocking, G.J., Jones, M.E., Lazenby, B., Mann, D., Mooney, N., Pemberton, D., Pyecroft, S., Restani, M. & Wiersma, J. 2006: Emerging disease and population decline of an island endemic, the Tasmanian Devil *Sarcophilus harrissi. Biological Conservation* **131:** 307–324.

Hyslop, E.J. 1980: Stomach contents analysis – a review of their methods and their application. *Journal of Fish Biology* **17**: 411–429.

Jarman, P.J., Allen, L.R., Boschma, D.J. & Green, S.W. 2007: Scat contents of the spotted-tailed quoll *Dasyurus maculatus* in the New England gorges, north-eastern New South Wales. *Australian Journal of Zoology* **55**: 63–72.

Jones, M.E. & Barmuta, L.A. 1998: Diet overlap and relative abundance of sympatric dasyurid carnivores: a hypothesis of competition. *Journal of Animal Ecology* **67**: 410–421.

Marshall, B. & Cosgrove, R. 1990: Tasmanian Devil (*Sarcophilus harrisii*) scat-bone: signature criteria and archaeological implications. *Archaeologica Oceania* **25**: 102–113.

Marvanek, S. 2006: A preliminary spatial analysis of Tasmanian Devils in light of Devil Facial Tumour Disease. Report to the Department of Primary Industries and Water from CSIRO: 35 pp.

Owen, D. & Pemberton, D. 2005: *Tasmanian Devil: a Unique and Threatened Animal.* Allen and Unwin, Sydney, Australia: 225 pp.

Pemberton, D. & Renouf, D. 1993: A field study of communication and social behaviours of the Tasmanian Devil at feeding sites. *Australian Journal of Zoology* **41**: 507–526.

Roberts, M.G. 1915: The keeping and breeding of Tasmanian Devils (*Sarcophilus harrisi*). *Proceedings of the Zoological Society of London*: **1915**: 575–581.

Taylor, R.J. 1986: Notes on the diet of the carnivorous mammals of the upper Henty River region, western Tasmania. *Papers and Proceedings of the Royal Society of Tasm*ania **120**: 7–10.

Terauds, A., Gales, R., Lee, D. & Irvine, A. in press: An assessment of documented causes of mortality of fur seals in Tasmania, Australia. *Wildlife Research.*

Triggs, B. 1996: *Tracks, Scats and Other Traces: a Field Guide to Australian Mammals.* Oxford University Press, Melbourne: 340 pp.

(accepted 7 October 2008)

UNUSUAL PEGMATOID CRYSTALLISATIONS IN A NEPHELINITE PLUG, NEAR ROUND LAGOON, EASTERN CENTRAL PLATEAU, TASMANIA

by F. L. Sutherland, B. J. Barron, R. E. Pogson, J. L. Everard, S. M. Forsyth and J. D. Hollis

(with five text-figures, two plates and six tables)

Sutherland, F.L., Barron, B.J., Pogson, R.E., Everard, J.L., Forsyth, S.M. & Hollis, J.D. 2008 (28:xi): Unusual pegmatoid crystallisations in a nephelinite plug, near Round Lagoon, eastern Central Plateau, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 23–38. ISSN 0080-4703. Geoscience, Australian Museum, 6 College Street, Sydney, New South Wales 2010, Australia (FLS*, REP); 7 Fairview Avenue, St Ives, Sydney, New South Wales 2075, Australia (BJB); Mineral Resources Tasmania, PO Box 56, Rosny Park, Tasmania 7018, Australia (JLE, SMF); "Shenley", 33 Park Street, Trentham, Victoria 3458, Australia (JDH). *Author for correspondence. Email: Lin.Sutherland@austmus.gov.au

Pegmatoids in a Late Oligocene olivine nephelinite plug near Round Lagoon form a complex low-pressure fractionation suite. The host nephelinite contains meta-peridotite and meta-wehrlite mantle xenoliths and its composition (Mg# 0.63) may reflect both mantle and then limited low-pressure fractionation. The pegmatoids range from ultramafic through mafic to feldspathic assemblages in a progressive, but discontinuous, fractionation sequence (wehrlite → olivine clinopyroxenite → sodalite ijolite, ijolite, nepheline syenite → alkali syenite). Within this sequence, olivine and clinopyroxene compositions decrease in Mg content, while clinopyroxene becomes increasingly Na- and Fe-rich to produce late stage aegirine-augite and aegirine. Nepheline is prominent in the sequence and crystallised over a wide temperature range from 1000° to <500°C. The presence of sodalite suggests volatile Cl-rich fluxing. Mg-rich spinel crystallised in early assemblages, distinct from Fe- and Ti-rich oxides of the magnetite-ulvospinel series in later assemblages. The Round Lagoon low-pressure pegmatoids developed by fractionation in a narrow, vertical feeder rather than in broad lava ponds such as those noted in nephelinite flows at Inverell, New South Wales, and at La Madera, Argentina.

Key Words: olivine nephelinite, fractionation, pegmatoids, feldspathoids, xenoliths, mantle, Tasmania.

INTRODUCTION

A diverse assemblage of mantle and crustal xenoliths and coarse-grained cognate feldspathoidal and feldspathic crystallisations has been briefly reported from an olivine nephelinite plug, on the eastern Central Plateau in Tasmania (Sutherland & Hollis 1982, Sutherland 1989, Sutherland *et al.* 1989, Everard 2001). The site lies 0.7 km east of Round Lagoon and 7 km north of Lake Sorell (Grid AMG 517600mE, 5348400mN, or 147°13.7'E, 42°00.9'S, datum AGD 66). The plug is a prominent, strongly east–west-jointed feature about 250 m across, which penetrates the eroded edge of the Jurassic dolerite sill, here about 300 m thick, which forms the Great Western Tiers. It extends from 960–1030 m asl, with its greatest exposure on the down slope side. Brecciated and altered dolerite is visible against the north side of the plug, suggesting intrusive emplacement of the nephelinite, but scree obscures the contact elsewhere. This olivine nephelinite plug was analysed and dated by the K-Ar method as Late Oligocene in age (24.9±0.2 Ma; Sutherland 1989). It is one of many basaltic plug and flow remnants mapped on the Interlaken 1:50 000 geological map sheet (Forsyth 1989). These lie west of the Tiers escarpment, formed by erosional retreat inland from the Tiers lineament that bounds the Midlands rift valley to the east (Direen & Leaman 1997). The lithospheric mantle below this region lies at a depth of about 30 km (Rawlinson *et al.* 2001).

The xenolithic and coarse cognate assemblages here form one of the most varied, and best preserved, inclusion suites in Tasmania. As well as containing fragments from the Jurassic dolerite and underlying Permian sandstones and shales, ultramafic mantle xenoliths, some cumulate-textured ultramafic to mafic pyroxenites, disaggregated xenocrysts, and coarse pegmatoidal feldspathoidal and feldspathic crystallisations also occur. The mantle xenoliths are dominated by spinel meta-lherzolite, mostly medium-grained, but finer grained types and recrystallised, partly glassy variants occur. Some olivine grains within them, up to 50 mm across, approach gem quality, but are mostly fractured. Some coarse spinel meta-lherzolites and pyroxenites exhibit lamellar exsolution of clinopyroxene in orthopyroxene. Mantle xenoliths reach up to 210 mm across. One has a composite structure (fig. 1), in which spinel meta-lherzolite is disrupted by cumulate crystallisations of transitional wehrlite (~40% olivine, 60% clinopyroxene) showing a cavity-like texture which have finer grained margins of clinopyroxenite (~olivine 5%, clinopyroxene 95%) against the host meta-lherzolite.

Abundant coarse-grained pegmatoids in the host nephelinite which have feldspathoidal and syenitic assemblages are the focus of the current investigation. One long pegmatoid vein traverses the plug, but most pegmatoids

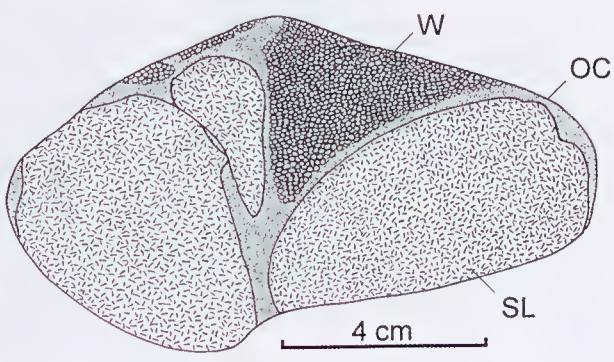


FIG. 1 — Composite mantle xenolith, showing spinel lherzolite (SL), intruded by finer grained margins of cumulate olivine clinopyroxenite (OC) and coarse cumulate wehrlite (W). Sketch by J.D. Hollis, redrawn by R.T. Springthorpe.

form discrete, subangular bodies up to a few cm across. Some rounded bodies contain internal radial growths and represent cavity fillings. Most, however, show abrupt, irregular contacts with the host. Such abundant feldspathoidal pegmatoids are rarely described from olivine nephelinites (London 2008). A single nepheline-sodalite-syenite pegmatoid from Boat Harbour, NW Tasmania (Sutherland *et al.* 1996), forms an isolated example. Pegmatoidal developments in nephelinite near Inverell, New South Wales (Wilkinson 1977), are not as mineralogically diverse as those at Round Lagoon. Abundant pegmatitic dykes occur in melanephelinite from Córdoba, Argentina (Galliski *et al.* 2004), but these are injections into a flow and differ in mineralogy to Round Lagoon pegmatoids. Pegmatoids and their low-pressure fractionation trends within olivine-melilite-nephelinite flows in Hawaii (Wilkinson & Stolz 1983) and western Bohemia (Ulrych *et al.* 2000) differ in that their assemblages include melilite. Alkali pyroxenite and ijolite materials in a nephelinite centre from Bohemia that were originally thought to be endogenous are now considered to represent a separate, deep-seated nephelinitic crystallisation (Ulrych *et al.* 2005).

This present paper documents the unusual Round Lagoon xenolith and pegmatoidal mineral assemblages, particularly the late-stage assemblages. The results are then used to evaluate the pegmatoidal assemblages in terms of fractionation trends described from nephelinites elsewhere and also compare the high-pressure ultramafic xenoliths with other Tasmanian and eastern Australian mantle suites. The term pegmatoid is preferred here over the term pegmatite, which includes much coarser assemblages associated with larger intrusive masses of alkaline and silicic rocks (London 2008).

MATERIALS AND ANALYTICAL METHODS

Thin sections and polished thin sections were prepared from samples housed in the Australian Museum collections. The study suite with sample numbers is listed in table 1. Two electron microprobe (EMP) facilities were used for mineral analyses. Analyses made on automated ETEC microprobe at Macquarie University, North Ryde, used natural standards, Bence-Albee matrix corrections, a 15 kV accelerating voltage and a sample current of 20 nA (B.J. Barron, analyst). Supplementary analyses under similar settings employed a combined wave length energy dispersive system at the Electron Microscope Unit, University of Sydney, with wave length spectrometers used to improve detection limits on key elements such as Na and K (D.F. Hendry, analyst). These methods gave precisions better than ±1 relative % for elements above 10 wt.% as oxides, ±5% for elements between 1–10 wt.% as oxides and ±10% for elements below 1 wt.%

TABLE 1
Samples studied from Round Lagoon nephelinite plug

Sample	Nature	Examination[1]	Designation[2]	Origin
RL1	Peridotite	TS, OM, PM	Spl-wehrlite	Cumulate
RL1A	Pyroxenite	TS, OM, PM	Ol-ne-clinopyroxenite	Cumulate
	Foid-syenitoid		Ijolite[3,4]	Late-stage
RL2	Peridotite	TS,OM	Spl- wehrlite	Cumulate
RL2A	Foid-syenitoid	TS,OM, EMP, PM	Ijolite[3]	Late-stage
RL3	Foidolite	TS,OM, EMP, PM	Sdl-ijolite[4]	Late-stage
RL3A	Nephelinite host	TS,OM, EMP	Ol-nephelinite[3]	Eruptive
RL3B	Pyroxenite	TS,OM	Ol-ne-clinopyroxenite	Cumulate
RL4	Foidolite	TS,OM	Ijolite[3]	Late-stage
RL5	Pyroxenite	TS,OM	Ol-ne-clinopyroxenite	Cumulate
RL6	Foid-syenitoid	TS,OM, EMP, PM	Ne-syenite[3]	Late-stage
RL6A	Peridotite	TS,OM, EMP, PM	Spl-wherlite	Meta-mantle
RL7	Pyroxenite	TS,OM	Spl-ol-clinopyroxenite	Meta-mantle
RL7A	Foid-syenitoid	TS,OM	Ne-syenite[3]	Late-stage
RL8	Peridotite	TS,OM, EMP, PM	Spl-wehrlite[4]	Cumulate
RL9	Peridotite	TS,OM, EMP, PM	Spl-lherzolite	Meta-mantle
RL10	Pyroxenite	TS,OM	Ol-clinopyroxenite	Cumulate
RL11	Foid-syenitoid	TS,OM	Ne-syenite	Late-stage
RL12	Foid-syenitoid	TS,OM,	Ne-syenite	Late-stage
RL13	Pyroxenite	TS,OM	Spl-clinopyroxenite	Meta-mantle
RL14	Pyroxenite	TS,OM	Spl-ol-websterite	Meta-mantle
RL15	Microsyenitoid	TS,OM, EMP, PM	Alkali syenite[3,4]	Late-stage
RL16	Pyroxenite	TS,OM	Spl-websterite	Meta-mantle
RL17	Peridotite	TS,OM	Olivine megacryst	Meta-mantle
RL18	Peridotite	TS,OM	Spl-lherzolite	Meta-mantle
RL19	Pyroxenite	TS,OM, EMP, PM	Ol-clinopyroxenite	Cumulate

[1] TS, thin/polished section; OM, optical microscopy; EMP, electron microprobe; PM, photomicrograph.
[2] Spl, spinel. Ol, olivine. Ne, nepheline. Sdl, sodalite.
[3] Afd, alkali feldspar. [4] Amp, amphibole.

as oxides. Comparative analyses from the two instruments mostly agreed within ±2% for oxides above 5 wt.%, within ±8% for oxides between 1–4 wt.% and ±30% for oxides below 1 wt.%. A semi-quantitative Energy Dispersive X-ray Spectrometer (Oxford Instruments Link Isis 200) at the Australian Museum, Sydney (R.E. Pogson, analyst), was used to determine the Cl content of sodalite. Photomicrographs of sections were taken using a Leica DMLP petrographic microscope, with a digital image capture systems, at the Australian Museum (pls 1, 2).

Representative analyses selected from the wider EMP data set are listed for the essential petrological assemblages in tables 2–5. The geochemical data were plotted on triangular plots and discrimination diagrams, using Geo Plot (Zhou & Li 2006). Mineral nomenclature follows International Mineralogical Association guidelines. End members for olivine are based on Deer *et al.* (1982). Pyroxene names are based on Morimoto (1988) and the computer program of Cebeira (1990). Amphibole names are based on Leake *et al.* (1997) and the computer program of Yavuz (1996). Rock names follow general recommendations in Le Maitre (2002) and for Australian intraplate volcanic rocks those in Johnson (1989). Normative mineral abbreviations follow those in Hutchison (1974), while symbols for rock-forming minerals follow Kretz (1983).

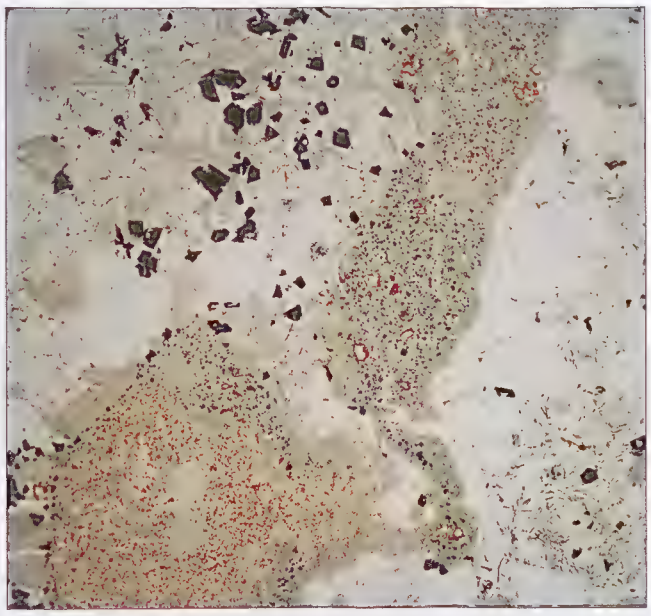


PLATE 1
Photomicrograph of olivine clinopyroxenite (bottom left) and surrounding sodalite-ijolite (right) and ijolite (top left) crystallisations in host olivine nephelinite (centre). Field of view 23 mm wide X 22 mm high. R.E. Pogson photograph.

PETROGRAPHIC RESULTS

Host nephelinite

The nephelinite contains olivine and clinopyroxene microphenocrysts up to 2 mm across in a groundmass of granular olivine, prismatic clinopyroxene, granular to subhedral equant opaque oxide grains and interstitial and partly sub-ophitic to poikilitic nepheline and alkali feldspar. Acicular apatite and small ragged flakes of dark mica are accessories. Mineral analyses (table 2) show the olivine is forsterite (fo_{72-74}), partly corroded and altered to "iddingsite". Clinopyroxene is zoned titaniferous augite-diopside (en_{41-49} $di_{40-49}fs_{10-11}$; TiO_2 2–3 wt.%) with simple to multiple twinning and partially resorbed cores in phenocrysts. Opaque oxide is magnetite-ulvospinel, which forms sporadic clusters. Nepheline is sodic ($ne_{80-81}kls_{14-15}qtz_{2-3}$); alkali feldspar is zoned from anorthoclase to sanidine ($or_{52}ab_{47}an_1$). Although overlapping, the crystallisation sequence is: olivine, clinopyroxene, ulvospinel, apatite, nepheline, alkali feldspar and zeolites.

Ultramafic cumulates

These comprise wehrlites and olivine-clinopyroxenites. The wehrlites (RL1, 2, 8; table 2; pl. 2A) contain up to 85% olivine ($fo_{90-91}fa_{9-10}$) as coarse, granular grains up to 5 mm across and as smaller inclusions in branching domains of microgranular pale green Cr-bearing augite ($en_{54-55}wo_{40-42}fs_4$; Cr_2O_3 2.2–2.5 wt.%). Accessory interstitial yellow-brown Cr-bearing spinel ($spl_{82-83}chr_{13-14}usp_2mag_{1-2}hc_1$) exhibits opaque reaction rims. Residual, branching networks and veinlets through the assemblage are composed of glassy, low relief material that contains rare phlogopite grains (Mg # 0.87), alkali feldspar, saponitic clays and other alteration products.

The olivine-clinopyroxenites (RL1A, 3B, 5, 10, 19; table 2; pl. 2B) contain intergrown crystals of Ti- and Al- bearing diopside ($wo_{51-57}en_{37-38}fs_{10-12}$; Al_2O_3 5.2–5.6 wt.%, TiO_2 2.3–2.8 wt.%), commonly up to 8 mm across or more in some cases. They include small grains of olivine (fo_{73}). Interstitial and vein-like intergrowths consist of sodic nepheline ($ne_{76-77}kls_{13-15}qtz_{10}$) and accessory alkali feldspar, ulvospinel, apatite and rare brown mica. These may form along zones of alteration in diopside. In contact with the host nephelinite, the diopside has euhedral overgrowths which lack inclusions. Rare, composite diopside aggregates show crystal growth radiating out from a nucleus of sodalite, alkali feldspar and poikilitic nepheline that encloses small olivine grains.

A notable composite pegmatoid in the host nephelinite (RL1A) contains a nepheline-olivine-bearing clinopyroxenite core within flanking ijolite and nepheline syenite pegmatoid. This illustrates a localised fractionation process within crystallising nephelinite (pl. 1).

Feldspathoid-rich pegmatoids

These foidolites range from sodalite- and nepheline-rich assemblages to nepheline-rich assemblages containing minor alkali feldspar. Typical sodalite- ($sdl_{93}k\text{-}sdl_7$) and nepheline ($ne_{67-68}kls_{29-30}qtz_3$)-rich examples (RL3, table 3, pl. 2C) contain about 50% interstitial feldspathoids (nepheline slightly exceeds sodalite) and 50% stumpy subhedral to euhedral pale yellow diopside ($wo_{46-49}en_{33-43}fs_{9-19}$), partially grading to pinkish Ti-bearing (TiO_2 2 wt.%) and dark blue-green sodic pyroxene on its rims and in adjacent grains ($acm_{53-57}wo_{17-21}en_{10-15}fs_{8-11}jd_2$). The diopside contains small inclusions of olivine (fo_{65-66}), accessory ulvospinel and aegirine-augite.

Nepheline- and alkali feldspar-rich assemblages (RL 1A, 2A, 4, 6, 11, 12; table 3, pl. 2E) contain nepheline ($ne_{82-83}kls_{15-16}qtz_2$) as oriented narrow hexagonal prismatic crystals in coarser anhedral anorthoclase ($ab_{59-61}or_{33-35}an_6$) and associated domain-zoned, anhedral pale purple Ti- and Al-bearing diopside ($wo_{50-52}en_{36-41}fs_{9-13}$; TiO_2 2–4 wt.%,

A
B
C
D
E
F
G
H

TABLE 2
Representative analyses host nephelinite and ultramafic cumulates

Analysis wt.%	Ol-nephelinite (RL3A)[1]			Wehrlite (RL8)[2]				Olv-clinopyroxenite (RL19)[3]		
Mineral	Ol	Cpx	Ne	Ol	Cpx	Spl	Clay	Cpx	Ol	Ne
SiO_2	38.62	48.95	44.33	40.82	54.88	0.59	38.12	49.03	38.35	47.48
TiO_2		2.42	0.16			0.14		2.33	0.04	0.06
Al_2O_3		5.14	32.64			53.69	15.19	5.34		31.67
Cr_2O_3		0.24			2.55	13.51	0.10	0.29		
FeO	20.39	6.04	0.85	8.74	2.66	9.18	0.29	4.98	24.32	0.76
Fe_2O_3						1.69		1.20		
MnO	0.27				0.17		0.11	0.12	0.77	0.09
MgO	40.14	13.69		49.57	18.39	21.01	25.88	12.67	36.62	0.26
CaO	0.32	22.07	0.88	0.13	18.73		0.71	24.18	0.26	0.32
Na_2O		0.68	16.48		1.26			0.41		15.32
K_2O			4.15					0.05		3.86
Total	99.74	99.23	99.49	99.26	99.11	99.81	80.40	100.50	100.36	99.82
Cations (No. O)	4	6	32	4	6	32	20	6	4	32
Si^{4+}	0.999	1.826	8.500	1.002	1.998	0.124	5.336	1.814	1.005	8.945
Ti^{4+}		0.068	0.023			0.021		0.065	0.001	0.009
Al^{3+}		0.226	7.379			13.215	2.506	0.233		7.035
Cr^{3+}		0.007			0.073	2.231	0.011	0.009		
Fe^{2+}	0.441	0.152	0.136	0.179	0.081	1.603	0.034	0.154	0.533	0.120
Fe^{3+}		0.036				0.2648		0.033		
Mn^{2+}	0.006				0.005		0.013	0.004	1.431	0.014
Mg^{2+}	1.547	0.761		1.813	1.023		5.399	0.699	0.007	0.073
Ca^{2+}	0.009	0.882	0.180	0.003	0.730	6.566	0.106	0.958		0.065
Na^{1+}		0.049	6.126		0.089			0.029		5.598
K^{1+}			1.015					0.002		0.928
Sum	3.001	4.007	23.358	2.998	4.001	24.098	12.405	4.000	2.994	22.790
Cation ratio (%)										
Mg	77.5	41.5		90.8	55.8	61.3	97.5	37.8	73.0	
Fe	22.1	10.3		9.0	4.4	17.7	0.6	10.3	27.0	
Cr						21.0				
Ca	0.4	48.2	2.46	0.2	39.8		1.9	51.9		0.9
Na			83.7							85.0
K			13.9							14.1

[1] **RL3A** Ol: Forsterite ($fo_{78}fa_{22}$); Cpx: Diopside ($wo_{48}en_{42}fs_{10}$); Ne: Nepheline ($ne_{80}kls_{14}qtz_6$).
[2] **RL8** Ol: Forsterite ($fo_{91}fa_9$); Cpx: Augite ($en_{55}wo_{40}fs_5$); Spl: Cr-rich spinel ($sp_{82}chr_{14}usp_2mag_2hc_1$);
[3] **RL19** Cpx: Diopside ($wo_{52}en_{38}fs_{10}$); Ol: Fosterite ($fo_{73}fa_{27}$); Ne: Nepheline ($ne_{77}kls_{13}qtz_{10}$).

PLATE 2 (opposite page)
Photomicrographs of selected pegmatoid and xenolith textures within the Round Lagoon nephelinite. Field of view for each image, 5 mm wide X 3.5 mm high. A. Wehrlite (RL8), with olivine (large grains), Cr-rich augite (long crystals, centre and bottom left) and Cr-bearing spinel (opaque grain, centre top). B. Olivine-nepheline-clinopyroxenite (RL 19) with diopside (large grains) riddled with olivine (small crystals, light and dark altered grains) and nepheline (light coloured crystals). C. Sodalite ijolite (RL3) with nepheline and sodalite (light crystals), diopside (spongy included cores), Ti-rich diopside (rims), aegirine-augite (dark overgrowths, bottom right) and ulvospinel (opaque interstitial crystals, top). D. Ijolite (RL2A), with nepheline and anorthoclase (light crystals), strongly zoned Ti-rich diopside (dark crystals). E. Nepheline syenite (RL6), with nepheline (light aligned crystals),sanidine (light coloured enclosure, centre left), diopside (intergrown darker area) and ulvospinel (large crystals, bottom left). F. Alkali syenite (RL15) with sanidine (light aligned crystals), diopside (small crystals top centre) and aegirine-augite and aegirine (dark intergrowth). G. Spinel meta-lherzolite (RL9) with olivine (large crystal, centre bottom), diopside (crystal centre top) and orthopyroxene (centre right and top left). H. Altered meta-wehrlite (RL6A) with olivine (crystals top right and bottom left), diopside (crystals bottom right), Cr-bearing spinel (black irregular grains) and extensive fine grained recrystallised zones. All images taken in plane polarised light. R.E. Pogson photographer.

TABLE 3
Representative mineral analyses, ijolitic pegmatoids

Analysis wt.%	Sodalite ijolite (RL3)					Ijolite (RL2A)				
Mineral	Ne	Sdl	Cpx[1]	Cpx[2]	Ol	Nep	Afd	Cpx	Ol	Spl
SiO_2	42.10	38.19	54.73	51.60	37.20	42.18	62.73	47.47	37.42	0.65
TiO_2			0.20	3.97			0.44	3.42	0.02	21.26
Al_2O_3	33.19	30.89	0.22	0.35	0.03	34.26	20.71	4.95	0.05	0.60
Cr_2O_3			0.12					0.09	0.05	0.77
FeO	1.04	0.72	5.98	16.67	28.56	0.86	0.38	7.36	21.70	46.38
Fe_2O_3				7.12						27.39
MnO		0.01	0.12	0.09	0.85	0.03	0.01	0.20	0.54	0.61
MgO	0.39		14.89	3.24	31.67	0.17	0.01	12.50	39.15	2.74
CaO	0.06	0.10	24.04	7.19	0.74	1.64	1.29	23.55	0.52	0.79
Na_2O	14.00	21.89	0.14	9.29		16.40	6.62	0.46		
K_2O	8.72	2.39	0.09			4.50	5.87	0.02		
Cl		7.37								
O≡Cl		−1.66								
Total	99.50	99.89	100.53	99.49	99.05	100.04	98.06	100.29	99.45	101.19
Cations (No. O)	32	26 (+Cl)	6	6	4	32	32	6	4	32
Si^{4+}	8.239	6.179	2.008	1.982	1.012	8.109	11.496	1.774	0.981	0.188
Ti^{4+}			0.006	0.115			0.061	0.096	0.000	4.634
Al^{3+}	7.655	5.890	0.010	0.016	0.001	7.763	4.473	0.218	0.002	0.205
Cr^{3+}								0.003	0.001	0.177
Fe^{2+}	0.17	0.097	0.184	0.229	0.650	0.138	0.058	0.156	0.476	11.243
Fe^{3+}				0.482				0.074		5.974
Mn^{2+}		0.001	0.004	0.003	0.020	0.005	0.002	0.006	0.012	0.150
Mg^{2+}	0.114		0.814	0.186	1.284	0.049	0.003	0.696	1.530	1.184
Ca^{2+}	0.013	0.017	0.945	0.296	0.022	0.338	0.253	0.943	0.015	0.245
Na^{1+}	5.312	6.867	0.010	0.692		6.113	2.352	0.035		
K^{1+}	2.177	0.493	0.004			1.104	1.372	0.001		
Cl		2.021								
Sum	23.680	21.565	3.989	4.001	2.989	23.619	20.070	4.002	3.017	24.000
Cation ratio (%)										
Mg			42.0	11.7	64.9			37.2	76.1	11.3
Fe			9.3	44.8	35.0			12.3	23.9	73.1
Ti										15.6
Ca	0.1	0.2	48.7	43.5	0.1	4.5	6.3	50.5	0.0	
Na	70.8	93.2				80.9	59.2			
K	29.0	6.6				14.6	34.5			

RL3 Ne: Nepheline ($ne_{67}kls_{30}qtz_3$); Sld: Sodalite ($sld_{93}k\text{-}sld_7$); Cpx[1]: Diopside ($wo_{49}en_{42}fs_9$); Cpx[2]: Aegrine-augite ($acm_{54}wo_{20}en_{15}fs_9jd_2$); Ol: Forsterite ($fo_{65}fa_{35}$);
RL2A Ne: Nepheline ($ne_{83}kls_{15}qtz_{22}$); Afd: Anorthoclase ($ab_{59}or_{35}an_6$); Cpx: Diopside ($wo_{51}en_{37}fs_{12}$); Ol: Forsterite ($fo_{76}fa_{24}$); Spl: Ulvospinel ($usp_{60}mag_{19}mf_{18}hc_1chr_1$)

Al_2O_3 1–7 wt.%). Ulvospinel ($usp_{42-61}mf_{17-33}mag_{8-20}hc_{1-14}chr_{1-4}$) forms sparse, large anhedral grains and is also present as inclusions in olivine (fo_{76-78}). Apatite is common as inclusions in the diopside.

Syenitic pegmatoids

These occur as nepheline-bearing and nepheline-free syenitic assemblages. The nepheline-bearing assemblages (RL2A, 7A, 11; table 4, pl. 2D) are dominated by coarse-grained, zoned subhedral to euhedral prismatic, pale brown to green rimmed, Ti-Al-bearing diopside ($wo_{48-51}en_{38-42}fs_{10-12}$; TiO_2 1.9–3.0 wt.%, Al_2O_3 3.0–6.5 wt.%). The central parts of these are crowded with inclusions, some being forsteritic olivine, and some outer rims pass into green sodic pyroxenes. The pyroxenes are embedded in coarse-grained, zoned sodic sanidine ($or_{52-53}ab_{4-47}an_1$), subhedral nepheline ($ne_{81-83}kls_{14-5}qtz_{3-5}$) and ulvospinel ($usp_{47-55}mag_{27-34}mf_{19-34}hc_{0-1}chr_{0-1}$) grains. Subordinate mesostasis and brown glass contain apatite and traces of biotite.

Syenites lacking nepheline (RL15; table 4, pl. 2F) are relatively rare among the pegmatoids. Some contain orientated, partly radial, intergrowths of sanidine laths ($or_{48-52}ab_{47-51}an_{0-1}$) and elongate diopside blades ($wo_{48-49}en_{41-42}fs_{9-10}$; TiO_2 up to 1.2 wt.%). The diopside develops outer rims and tips of more sodic green to dark green pyroxenes with compositions of aegirine-augite ($acm_{23-38}jd_{0-2}cf_{0-2}wo_{29-35}en_{22-29}fs_{9-11}$) and aegirine ($acm_{78-83}jd_{2-3}wo_{11}en_{6-10}fs_0$). Accessory green-brown amphibole grains range from titanian richterite and titanian ferro-richterite to potassic-titanian-richterite and titanian-magnesiokatophorite.

TABLE 4
Representative mineral analyses, ne-syenitoid and syenitoids

Analysis wt.%	Nepheline syenite (RL6)					Alkali syenite (RL15)				
Mineral	Afd	Ne	Cpx	Spl	Ol	Afd	Cpx^1	Cpx^2	Cpx^3	Amp
SiO_2	66.29	44.06	51.31	0.66	38.62	65.80	53.98	51.34	50.65	50.84
TiO_2	0.24		2.15	15.95		0.32	0.26	1.38	3.31	4.76
Al_2O_3	18.75	33.51	3.04		0.22	18.12	0.44	0.33	0.36	1.21
Cr_2O_3			0.19							
FeO	0.72	0.88	6.13	40.30	22.01	1.56	3.92	5.49	0.00	14.33
Fe_2O_3				38.44			2.37	12.88	26.35	
MnO				1.03	0.46		0.20	0.31	0.15	0.16
MgO			13.94	3.38	38.46	0.12	15.07	7.82	3.35	13.15
CaO	0.18	0.54	23.17	0.15	0.82	0.04	24.38	14.25	5.04	4.97
Na_2O	5.31	16.93	0.56			5.47	0.54	5.26	11.39	6.92
K_2O	8.99	4.36				8.55	0.02	0.08	0.03	1.38
Total	100.48	100.29	100.49	99.91	100.59	99.98	100.94	99.14	100.63	97.72
Cations (No. O)	32	32	6	32	4	32	6	6	6	23
Si^{4+}	11.932	8.396	1.892	0.195	0.999	11.937	1.981	1.964	1.911	7.514
Ti^{4+}	0.032	7.528	0.060	3. 538		0.044	0.007	0.040	0.094	0.529
Al^{3+}	3.980	0.140	0.132		0.007	3.874	0.019	0.015	0.016	0.211
Cr^{3+}			0.006							
Fe^{2+}	0.018		0.189	9.942	0.476	0.237	0.120	0.176	0.000	1.771
Fe^{3+}				8.534			0.065	0.371	0.748	0.000
Mn^{2+}				0.257	0.010		0.006	0.010	0.005	0.020
Mg^{2+}			0.766	1.486	1.483	0.032	0.820	0.446	0.188	20897
Ca^{2+}	0.036	0.112	0.915	0.047	0.023	0.008	0.954	0.584	0.204	0.787
Na^{1+}	0.463	6.256	0.040			1.924	0.038	0.390	0.833	1.983
K^{1+}	1.852	1.060				1.979	0.001	0.004	0.001	0.260
Sum	20.004	23.496	4.000	27.455	2.997	20.035	4.001	4.000	4.000	15.972
Cation ratio (%)				23.981						
Mg			41.0	6.3	74.9		41.6	28.4	11.4	43.7
Fe			10.1	78.5	24.0		9.6	34.6	41.9	26.4
Ti				15.1						
Ca	0.9	1.5	48.9		1.1	0.3	48.7	37.0		
Na	46.9	84.2				49.2			46.7	29.9
K	52.2	14.3				50.5				

RL6 Afd: Sanidine ($or_{52}ab_{47}an_1$); Ne: Nepheline ($ne_{81}kls_{15}qtz_5$); Cpx: Diopside ($wo_{49}en_{41}fs_{10}$); Spl: Ulvospinel ($usp_{47}mag_{34}mf_{19}$); Ol: Forsterite ($fo_{75}fa_5$).
RL15 Afd: Sanidine ($or_{51}ab_{49}an_0$); Cpx^1: Diopside ($wo_{49}en_{42}fs_{10}$); Cpx^2: Aegirine-augite ($acm_{37}wo_{29}en_{22}fs_9jd_2$); Cpx^3: Aegirine ($acm_{78}wo_{11}en_{10}jd_2fs_0$); Amp: Potassian-titanian-richterite.

Mantle meta-assemblages

These coarse-grained metamorphic assemblages are mostly spinel meta-lherzolite, but include spinel meta-wehrlite and spinel meta-websterite. The spinel meta-lherzolites (RL9, RL18, table 5, pl. 2G) consist of anhedral aggregates of olivine (fo_{88-89}), Al-Cr-bearing diopside ($wo_{50-52}en_{44-46}fs_{4-5}$; Al_2O_3 5.0–5.2 wt.%, Cr_2O_3 0.8–1.0 wt.%) and Al-bearing enstatite ($en_{88-89}fs_{10-11}wo_1$), interspersed with accessory Cr-bearing spinel ($spl_{70}chr_{14}hc_7$). The enstatite includes blebs and lamellae of Al-bearing diopside ($wo_{48-50}en_{45-47}fs_5$; Al_2O_3 5 wt.%), which gave estimated metamorphic re-equilibration temperatures of 890–950°C (Wells 1977, two-pyroxene Fe^{2+} thermometry).

Spinel meta-wehrlites (RL6A; table 5; pl. 2H) contain anhedral olivine (fo_{88-89}) and Cr-Al-bearing diopside ($wo_{49-50}en_{46-47}fs_4$; Al_2O_3 1.3–2.3 wt.%, Cr_2O_3 1.0–1.1 wt.%) and some interstitial Cr-bearing spinel ($spl_{73}chr_{10}hc_9mag_6$). The diopsides are spongy and partly replaced by melting reactants.

Many of the metamorphic assemblages show considerable recrystallisation and alteration related to reactions with fluid infiltrations from the host nephelinite. Recrystallisation is accompanied by replacement of the coarser phases by small olivine, clinopyroxene and ulvospinel grains, formation of sporadic large anhedral green spinel grains and development of a glassy melt. Initial reaction takes place along grain boundaries, but become more complex as clinopyroxenes and spinels develop sieve texture and orthopyroxene reacts to form replacement rims and glassy melt textures. Similar reactants were described in mantle suites in Boat Harbour, NW Tasmania, olivine nephelinite (Sutherland *et al.* 1996) and the compositions of such products have been reproduced experimentally at low pressure (Shaw & Dingwell 2008).

TABLE 5
Representative mineral analyses, meta-peridotites

Analysis wt.%	Spinel lherzolite (RL9)							Meta-wehrlite (RL6A)		
Mineral	Ol	Cpx	Opx^1	Cpx^1	Opx^2	Cpx^2	Spl	Ol	Cpx	Spl
SiO_2	41.19	52.20	55.23	52.06	54.93	52.06		40.70	54.31	0.37
TiO_2	0.10	0.54	0.13	0.60	0.14	0.63	0.18		0.21	0.16
Al_2O_3		5.03	3.67	4.98	3.76	5.14	56.29		1.28	53.49
Cr_2O_3		1.03	0.34	0.72	0.37	0.83	13.38		1.00	9.97
FeO	11.05	2.78	6.70	2.97	6.72	2.96	9.95	10.72	2.66	12.49
Fe_2O_3							0.23			5.40
MnO	0.19		0.14	0.08	0.25	0.02	0.03	0.22	0.07	0.29
MgO	47.31	14.67	31.77	15.46	31.51	15.16	20.44	48.38	16.34	18.74
CaO		22.59	0.43	22.34	0.39	22.53			24.55	
Na_2O		1.02		0.48		0.76			0.15	0.01
K_2O						0.04			0.04	
Total	99.84	99.86	98.41	99.69	98.07	100.13	100.50	100.02	100.62	100.92
Cations (No. O)	4	6	6	6	6	6	32	4	6	32
Si^{4+}	1.014	1.902	1.937	1.897	1.943	1.892		1.001	1.974	0.078
Ti^{4+}	0.002	0.015	0.003	0.016	0.004	0.017	0.028		0.006	0.025
Al^{3+}		0.216	0.152	0.214	0.156	0.220	13.721		0.055	13.215
Cr^{3+}		0.030	0.009	0.021	0.010	0.024	2.188		0.029	1.652
Fe^{2+}	0.228	0.085	0.197	0.091	0.198	0.090	1.721	0.220	0.081	2.190
Fe^{3+}							0.035			0.930
Mn^{2+}	0.004		0.004		0.008	0.001	0.005	0.005	0.002	0.052
Mg^{2+}	1.737	0.797	1.661	0.840	1.663	0.821	6.302	1.773	0.883	5.856
Ca^{2+}		0.882	.0.016	0.872	0.015	0.877			0.954	
Na^{1+}		0.072		0.034		0.054			0.011	
K^{1+}						0.002			0.002	0.003
Sum	2.985	3.999	3.979	3.99	3.997	3.998	24.000	2.999	3.997	24.000
Cation ratio (%)										
Mg	88.3	45.5	88.5	46.7	88.7	45.8	61.5	88.9	46.1	55.1
Fe	11.7	4.5	10.6	5.0	10.5	5.0	17.1	11.1	4.2	29.3
Ca	0.0	50.0	1.1	48.3	0.8	49.2		0.0	49.7	
Cr							21.3			15.6

RL9. Ol: Forsterite ($fo_{88}fa_{12}$); Cpx: Diopside ($wo_{50}en_{46}fs_5$); Opx^{-1}: Enstatite ($en_{89}fs_{11}wo_1$); Cpx^1: Diosipde ($wo_{48}en_{47}fs_5$); Opx^2: Estatite ($en_{89}fs_{11}wo_1$); Cpx^2: Diopside ($wo_{49}en_{46}fs_5$); Spl: Cr-rich spinel ($sp_{79}cm_{14}hc_7$). Opx^1-Cpx^1 Wells two-pyroxene (Fe^{2+}) T 947°C; Opx^2-Cpx^2 Wells two-pyroxene (Fe^{2+}) T 890°C
RL6A Ol: Forsterite ($fo_{89}fa_{11}$); Cpx: Diopside ($wo_{50}en_{46}fs_4$); Spl: spinel ($spl_{73}chr_{10}hc_9mag_6usp_6$).

DISCUSSION

The Round Lagoon nephelinite and contained coarse assemblages suggest its magmatic evolution took place under at least two different pressure-temperature regimes. The cumulate wehrlite and ol-clinopyroxenite bodies in the mantle meta-lherzolite xenolith (fig. 1) suggests a higher pressure, shallow mantle stage. Other cognate ultramafic to mafic assemblages, however, have mineral compositions similar to those in the host nephelinite that relate to later, lower pressure crystallisation.

Host nephelinite

This is a K-rich olivine nephelinite with a low $^{87}Sr/^{86}Sr$ (0.7302 ± 3) and is isotopically typical of many Tasmanian undersaturated alkaline lavas (McDonough *et al.* 1985, Sutherland 1989). In the spectrum of strongly undersaturated alkaline lavas in Tasmania, it has high SiO_2 content suggesting transition into basanite (fig. 2). The analysis has a high, near-primary Mg# (0.66), and relatively high Ni (341 ppm) and Cr (550 ppm). These apparently near-primary characteristics, however, are probably misleading due to many inextricable small xenocrysts of olivine and pyroxene, thus the rock does not represent a liquid composition. The magma was probably mildly fractionated, based on its olivine phenocryst compositions (up to fo_{78} which would be in equilibrium with a liquid of Mg # 0.51–0.52) and its relatively elevated incompatible elements; for example it has a Zr content (460 ppm) compared to Zr contents (<370 ppm) in other primary olivine nephelinites in Tasmania (Sutherland 1989, Sutherland *et al.* 1996, Sutherland *et al.* 2004, J. Everard, unpubl. data base). Available trace element data normalised to primitive mantle contents (fig. 3) compare closely with patterns for a fractionated olivine nephelinite (Mg# 0.59) and mantle-derived basanite (UT704489) from the Midlands area, and are higher in most of these elements than nephelinites from Boat Harbour. Based on the occurrence of the cumulate wehrlite and olivine clinopyroxenite found within the mantle xenolith suite, such fractionation was probably initiated at

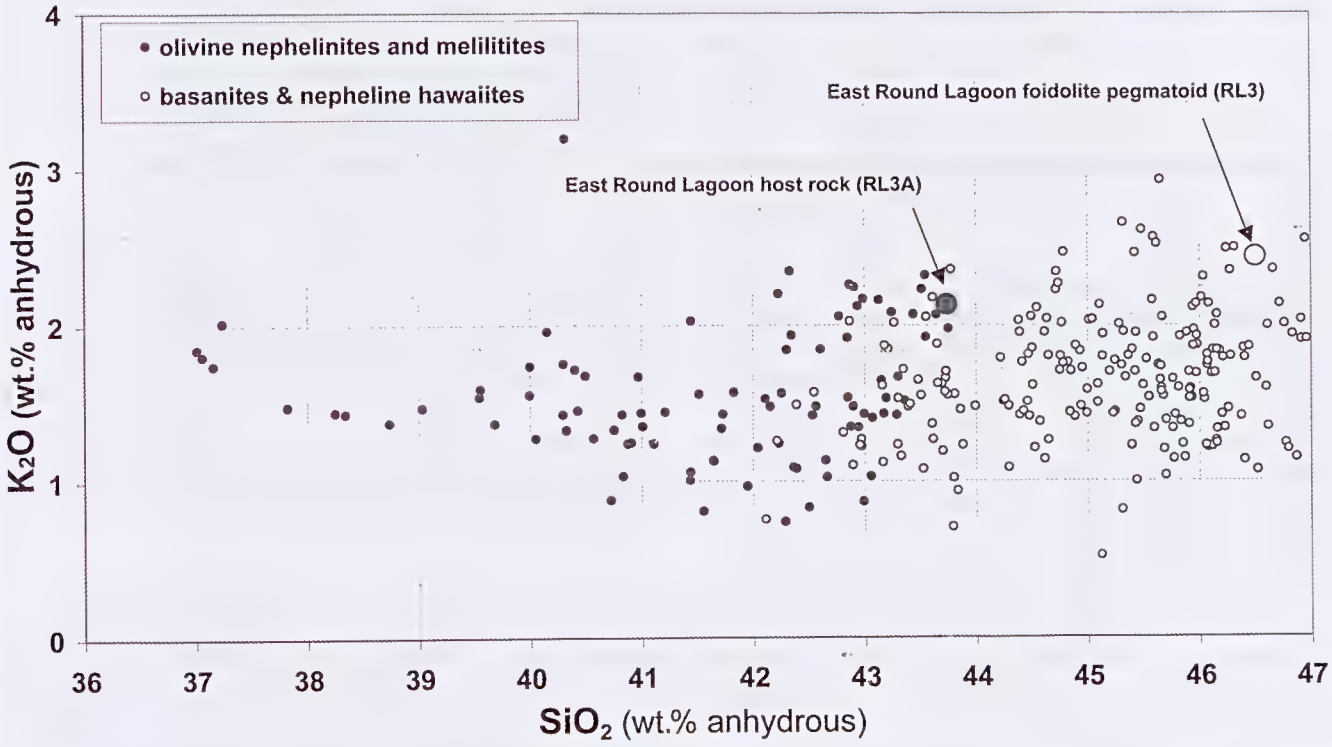


FIG. 2 — Alkali (K_2O) – SiO_2 (anhydrous) plots for Tasmanian melilitites and nephelinites, in relationship to the Round Lagoon nephelinite and sodalite ijolite (larger circles).

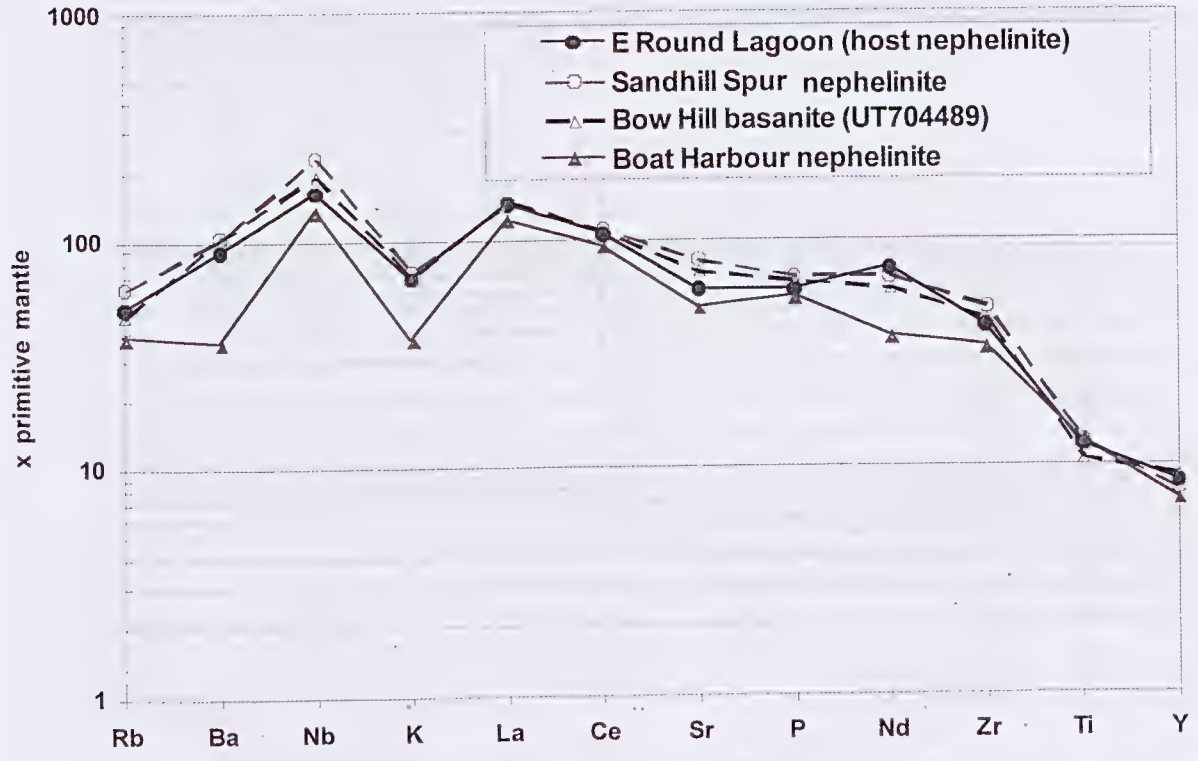


FIG. 3 — Incompatible multi-element plots for Round Lagoon nephelinite in comparison to other Tasmanian nephelinites and transitional basanites. Normalising factors are after Sun & McDonough (1989). Other data sources: Sandhill Spur (Sutherland et al. *2004), Bow Hill (Adam 1990) and Boat Harbour (Sutherland* et al. *1996).*

mantle depths under the site, although detailed rare earth element and isotopic analyses of both host and cumulate xenoliths are needed to confirm this. The mantle peridotites indicate a fast ascent of the nephelinite host, probably in the range of 10^{-2} to 5 m/s (Spera 1984). A primary composition of the original nephelinite magma could be provisionally estimated by adding in Mg-rich olivine, clinopyroxene ±spinel compositions found in wehrlite cumulates within the host nephelinite (table 2).

As proportions of such liquidus phases are only broadly constrained, two potential extracts were calculated; one had abundant olivine (65%), moderate clinopyroxene (30%) and accessory spinel (5%); the other had clinopyroxene (65%) dominant over olivine (30%), with accessory spinel (5%). The mineral compositions added from table 2 give potential magma compositions at 10% and 20% liquidus crystallisation. The olivine-dominant scheme gave Mg # 0.73 and 0.76 respectively, with high normative ol (24–28%), di (27–28%) and ne (13–15%) and or (10%). The clinopyroxene-dominant scheme gave Mg# 0.72 and 0.74 respectively, lesser normative ol (21–28%) to di (30–35%), but similar ne (14–15%) and or (10–12%) ranges. The latter parents resemble primitive mantle-derived olivine nephelinite (Mg # 0.73–0.75) in young Tasman Sea volcanism (Briggs *et al.* 1997).

The above calculated parent compositions would be partly modified under mantle conditions, in which more Al-Na-rich clinopyroxene typifies high-pressure liquidus phases. In ne-rich rocks and experimental runs on Tasmanian and other nephelinites such clinopyroxenes contain up to 10 wt.% Al_2O_3, 4 wt.% TiO_2 and 2 wt.% Na_2O (Bultitude & Green 1971, Fodor *et al.* 1982, Adam 1990, Sutherland *et al.* 1996, 2004, 2005, Woodland & Jugo 2007). Thus, a Round Lagoon mantle parent would have higher Al, Ti and Na than estimated from the low-pressure wherlitic extracts, but would be compatible with a high-pressure fractionation series in which sodic nephelinite magmas evolve to more K-rich members (Sutherland 1974). The Round Hill nephelinite, when adjusted for hydrous content, is near a Bow Hill, Tasmanian basanite in composition, which experimentally crystallised clinopyroxene at P>2.6 GPa and clinopyroxene and olivine at lower pressures in runs at 1270°C and 4.5 wt.% H_2O (UT-70489, Adam 1990). Based on such experimental work (Adam 1990, Green & Falloon 1998), the Round Lagoon magma probably segregated at 3 GPa (90 km depth) under low degrees of partial melting of garnet lherzolite that contained <7 wt.% volatiles (H_2O + CO_2). The nephelinite has high Ba, and to a lesser degree high Zr, Nb, and K. The Ba/Zr (1.4) and Ba/Nb (5.4) ratios are relatively high compared to some other Tasmanian nephelinites (Ba/Zr<1, Ba/Nb>3); which suggests either amphibole was low in the mantle source (Chazot *et al.* 1996), or that its contribution to the magma became diluted through the suspected mantle fractionation.

The lack of garnet or its replacements in Round Lagoon inclusions suggests the magma stalled and fractionated at mantle levels shallower than the spinel-garnet lherzolite transition, i.e., <1.7–1.8 GPa and 1100–1200°C for Tasmanian Miocene geotherms (Sutherland *et al.* 2005). The two-pyroxene temperatures for Round Lagoon spinel meta-lherzolite reach 950°C (table 5). Based on the Tasmanian geotherm, this suggests magma began to fractionate at around 1.0–1.1 GPa (30–35 km), at mantle depths shallower than the spinel-garnet pyroxenite transition. This agrees with a Moho depth at 30 km below the area. At these pressures, using the calculated CaO/(CaO+MgO) ratio of the nephelinite parental magma, the liquidus phases crystallising during this mantle fractionation would favour significant olivine along with clinopyroxene (Smith *et al.* 2008).

Low-pressure crystallisation

Clinopyroxenes in the Round Lagoon cumulate and pegmatoid assemblages mostly show relatively high Al^{IV}/Al^{VI} ratios (1.5–13.5). Such ratios typically indicate low-pressure igneous crystallisation, rather than mantle and lower crust pressures (Wass 1979, Mason 1985, Simonetti *et al.* 1996). The mantle xenolith clinopyroxenes give ratios of 1 or less, but some from wehrlitic cumulates have transitional values. Amphiboles in the pegmatoids also show high Al^{IV} and Ti, features that were found in lower pressure experimental runs of strongly undersaturated magmas (Adam *et al.* 2007).

Ultramafic crystallisation

Initial temperatures for crystallising liquidus minerals from such nephelinite magmas are about 1300°C for olivine, 1150°C for clinopyroxene and 1065°C for nepheline (Wilkinson 1977). These intervals cover the wehrlite (RL8) and ol-ne-bearing clinopyroxenite (RL19) assemblages. Olivine is highly magnesian (fo_{90-91}) in the wehrlites but less so in the clinopyroxenites (fo_{73}); the latter contains minor Ca_2SiO_4 and Mn_2SiO_4 end member components. Clinopyroxenes are Na-Cr-enriched augites in the wehrlites, but these elements are lower, and Ca and Fe higher in the diopside of the clinopyroxenites. Early nepheline in the clinopyroxenites is sodic (ne_{76-77}), and compositions suggest crystallisation around 980°C, based on experimental isotherms (Hamilton 1961). Estimates for crystallisation temperatures from nephelines, however, may be minimum values due to potential exchanges of alkalis and aqueous vapour that reset them to lower kls and qtz and so apparently lower temperatures (Edgar 1984).

Residual glass in the clinopyroxenites has an alkaline trachytic composition (table 6). Normatively this corresponds to minor Q (3%), Ab-rich plagioclase (43%) and Or (47%), together with accessory Hy, C, Mt and Il. Removal of MgO (1.9 wt.%) and FeO (1.2 wt.%) in the glass to crystallise spinel, leaves a remainder close to alkali feldspar in composition, with a stoichiometric formula approximating anorthoclase ($ab_{77}or_{21}an_2$). A potential spinel-bearing, anorthoclase-rich crystallisation from this glass is compatible with such phases observed in the more evolved pegmatoid (RL2A).

Main mafic crystallisation

Depletion of Mg, Ca and Fe and accumulation of alkalis and volatiles in the magma then produced sodic feldspathoidal-rich assemblages, such as sodalite-ijolite (RL3). Nepheline (Ne_{67-68}) in the sodalite-ijolites (RL3) is richer in K than in the nepheline-dominant ijolite (RL2A) and syenite (RL6) (fig. 4), as crystallising sodalite would compete for Na. Its composition suggests formation near 700°C based on experimental isotherms (Hamilton 1961). With up to 20% sodalite crystallisation, Cl was a significant volatile in the system. Crystallising pyroxene was accordingly Na-poor diopside, but incorporated Fe, Ti and Na to form late aegirine-augite (acm_{53-57}).

As feldspathoid crystallisation diminished, alkali feldspar ($ab_{59-61}or_{33-35}an_{6-7}$) became more important (fig. 4) in ijolitic assemblages (RL2A). Nepheline became more

TABLE 6
Major and trace element analyses, nephelinite host, foidolite and cumulate glass

Analysis	Major elements, CIPW norms and Indices			Trace elements (ppm)		
Oxides (wt.%)	Nephelinite[1]	Foidolite[1]	Glass[2]		Nephelinite[1]	Foidolite[1]
SiO_2	42.28	45.95	64.59	Cr	550	86
TiO_2	2.65	2.50	0.20	Ni	341	125
Al_2O_3	10.81	13.03	17.36	V	112	290
Fe_2O_3	3.94	4.92	0.21			
FeO	8.61	4.57	1.03	Ba	625	1100
MnO	0.20	0.15		Y	38	38
MgO	11.35	7.95	1.90	Sr	1269	1850
CaO	9.83	12.67	0.17	Zr	460	520
Na_2O	4.03	3.89	4.88	U	<2	<5
K_2O	2.06	2.41	7.81	Rb	32	68
P_2O_5	1.30	1.26		Th	9	<4
H_2O+	2.49	0.14		Pb	27	8
CO_2	0.28	0.37		Ga	24	19
Total	99.83	99.81	98.15	Nb	115	210
Na_2O/K_2O	1.96	4.10	0.62			
CIPW Norm (anhydrous, based on Fe_2O_3/FeO = 0.2)				La	98	NA
				Ce	187	NA
Q			2.53	Nd	100	NA
Or	12.56	14.38	47.02			
Ab	3.36	5.18	42.07	Zn	175	93
An	5.49	11.08	0.86	Cu	57	70
Ne	17.24	15.20	Hy 6.24			
Di	29.14	33.59		Trace element ratios		
Ol	20.77	8.53		Cr/Ni	1.613	0.689
Mt	3.08	2.23	0.31	Rb/Sr	0.025	0.037
Il	5.17	4.80	0.39	Zr/Nb	4.000	2.477
Ap	3.16	3.16		Ba/Nb	5.435	5.238
Other			C 0.58	Rb/Nb	0.278	0.324
				Th/U	>4.50	>0.80
				La/Y	2.5	
				Ce/Y	4.9	
Mg/ Mg+Fe^{2+}	0.663	0.650	0.766			
ΣOr, Ab, Ne, Q	33.16	34.76	91.62			
An mol. %	60.63	66.83	2.00			

Major and trace element analyses (RL3A, RL3) after Forsyth (1989)[1] and (RL 19)[2] this paper.

sodic (ne_{82-83}), with compositions suggesting T <500°C, based on experimental isotherms. Clinopyroxene remained diopsidic, but became more Ti- and Fe-rich. Mg-bearing ulvospinel (usp_{42-60}) formed the distinct Fe-Ti oxide. Such assemblages crystallising from hydrous nephelinitic magma would begin at around 880–890°C at 0.1 GPa, based on the diopside-albite-nepheline phase relationships (Patic *et al.* 2000) assuming sodic anorthoclase and albite are relatively close in composition. This is higher than the T indicated by the nepheline compositions, but the latter may be low due to hydrous vapour exchanges.

Feldspathic crystallisation

Alkali feldspar formed a principal K-rich phase (sanidine, or_{52-53}) in these assemblages (RL6), as Si, Ti, Fe and alkalis, particularly K, became concentrated with fractionation. Although subordinate, olivine remained magnesian (fo_{75}) while nepheline remained sodic (ne_{81-83}) with a composition similar to the low T (<500°C) nepheline in the host nephelinite. Clinopyroxene is Ti-enriched diopside and ulvospinel (usp_{47}) is the accessory oxide.

In the most evolved assemblages, K-rich alkali feldspar (or_{49-52}) appears without nepheline in alkali syenites (RL15). Clinopyroxenes enriched in Ti, Fe and Na on their rims, pass from strongly zoned diopside (fig. 5), through aegirine-augite (acm_{23-37}) into aegirine (acm_{78-83}). Amphiboles in the hydrous residues are K- and Ti- rich richterites. They are deficient in their cation sites, regardless of element and Fe valency assignments. Other elements not analysed in the EMP array may be present, as detected in certain amphibole associations elsewhere (Eggins *et al.* 1998, Preston *et al.* 2000), but such assignments remain problematic.

The feldspathic assemblages are commonly subspherical with the main phases radiating inwards from the margins, suggesting cavity infilling during final consolidation of the nephelinite. This contrasts with the irregular and vein-like mafic assemblages. These feldspathic residues resemble invariant point equilibrium assemblage compositions found for nephelinite-like compositions in the experimental diopside-albite-nepheline system at $P(H_2O)$ = P(Total) = 0.2 GPa (Patic *et al.* 2000).

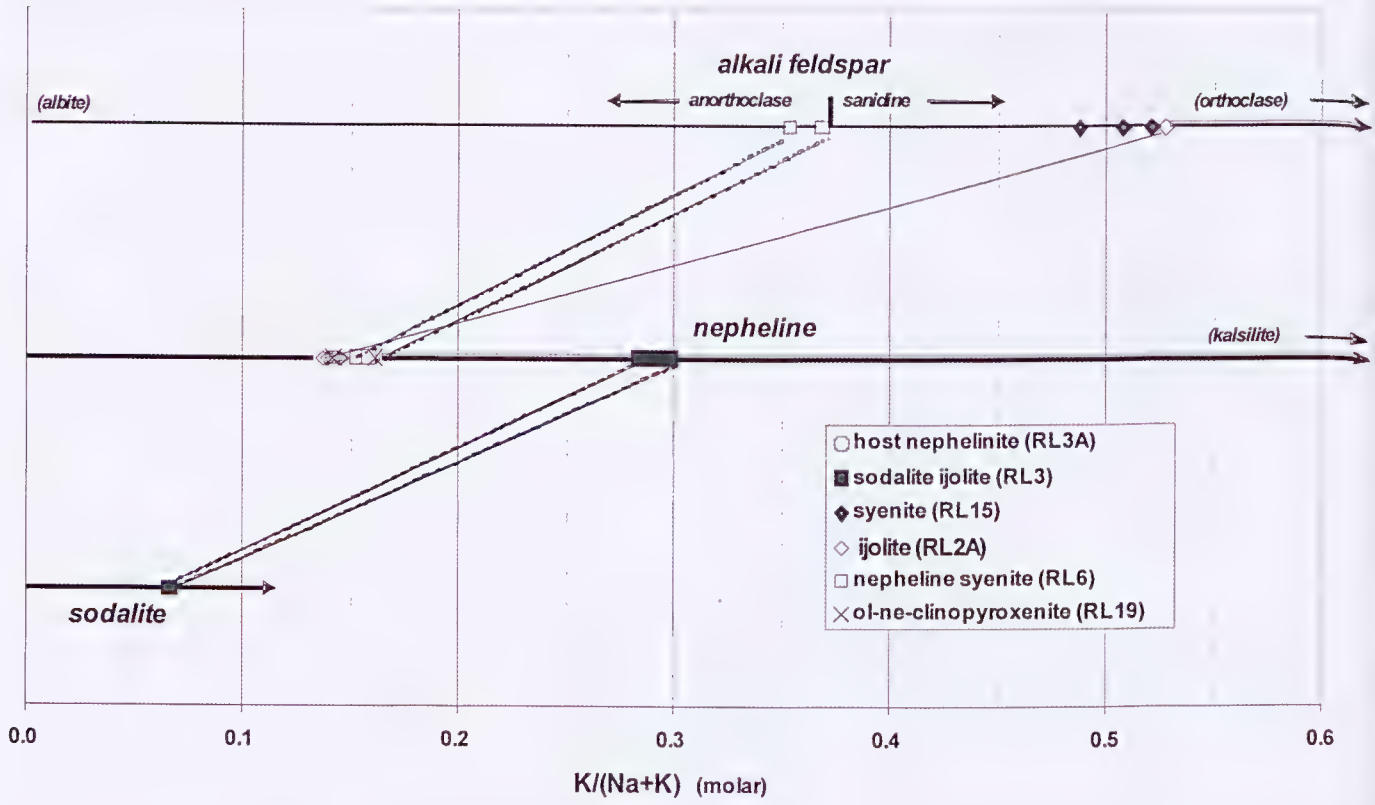


FIG. 4 — Plots of feldspathoid and feldspar compositions, from Round Lagoon nephelinite and pegmatoids: K/(Na + K) molar values for alkali feldspar, nepheline and sodalite, with symbols shown in legend for different samples. The various connecting lines link co-existing phases in the same sample.

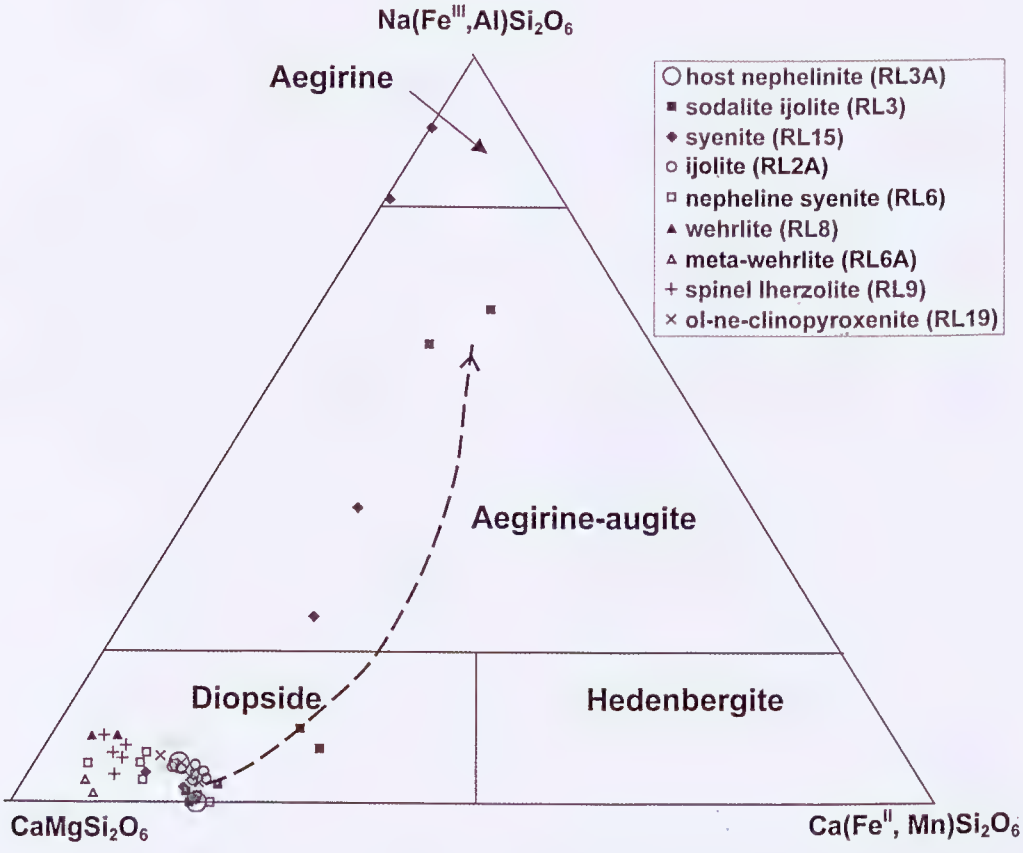


FIG. 5 — Compositional plots, Round Lagoon analysed pyroxenes, on a triangular end member Diopside – Hedenbergite – Aegirine diagram, with symbols after listed samples. The trend line of increasing Na is from analyses for Inverell, NSW, nephelinite and pegmatoids shown by Wilkinson (1977).

Fractionation sequence

The mineral paragenesis in the Round Lagoon fractionates suggests progressive, but discontinuous, crystallisation of assemblages within a cooling solidifying nephelinite magma, as follows: Wehrlites → Olivine-clinopyroxenites → Sodalite-ijolites → Ijolites → Nepheline syenites → Alkali syenites. Within this series, Mg depletion took place in olivines (fo_{91} → fo_{67}) and clinopyroxenes (en_{55} → en_{6}), which became more Na and Fe-rich (acm_{o} → acm_{83}). Accessory oxides were spinel (spl_{83} → spl_{1}; chr_{14} → chr_{1}) in ultramafic associations and magnetite-ulvospinel (mag_{1} → mag_{34}; usp_{2} → usp_{61}) in mafic and feldspathic associations.

Bulk analyses of the host and cognate assemblages are limited in this study, but a sodalite-ijolite analysis (table 6) defines some trends in major element composition with low-pressure fractionation (fig. 2). The depletions in Cr and Ni and enrichments in incompatible elements such as Ba, Sr, Rb, Zr and Nb reflect olivine, pyroxene and spinel crystallisation. The host and sodalite-ijolite bulk compositions do not show extensive separation related to prolonged olivine-clinopyroxene-nepheline crystallisation within the phase equilibrium nepheline-diopside-silica system (Wilkinson 1977). This may suggest rapid, non-equilibrium conditions prevailed during sodalite-ijolite crystallisation, probably initiated by a Cl-rich flux, perhaps accompanied by some magma mixing.

Comparisons with other nephelinite pegmatoids

Examples of pegmatoids in nephelinites in Tasmania, eastern Australia and basalt fields elsewhere are sparse (London 2008). Pegmatoids are also recorded in melilite-bearing or basanitic hosts as in the Shannon Tier melilitite and Table Cape teschenite (Sutherland *et al.* 2004). Transitional basanite nephelinites also contain coarse-grained differentiations (Wittke & Holm 1996). These pegmatoids, however, involve further Ca-rich phases such as melilite or plagioclase in their fractionation and only simpler nephelinite fractionates are considered here.

Australia

Pegmatoids in Tasmanian nephelinites are recorded at Boat Harbour, East Arm (Tamar River) and West Scottsdale, but detailed mineral analyses are only available for the Boat Harbour pegmatoid. That pegmatoid is transitional in mode between Round Lagoon sodalite-ijolite (RL3) and nepheline-syenite (RL6). Sodalite is less potassic (k-sdl_{1} *cf* k-sdl_{7}), nepheline is intermediate in K-content (kls_{19} *cf* kls_{15-30}) and alkali feldspar is more potassic (or_{21} *cf* or_{53-59}), while clinopyroxene has higher Mg (en_{47} *cf* en_{41-42}) and olivine intermediate Mg (fo_{72} *cf* fo_{64-75}), compared to Round Lagoon phases. Nepheline compositions suggest similar crystallisation temperatures to those in the sodalite-ijolite pegmatoid at Round Lagoon (~700°C).

Melanocratic and leucocratic pegmatoids at Inverell (Wilkinson 1977) respectively resemble ijolite (RL2A) and nepheline-syenite (RL6) at Round Lagoon. Inverell melanocratic variants, however, have less sodic nepheline (ne_{79} *cf* ne_{83}) and more potassic alkali feldspar (or_{57-64} *cf* or_{37-52}), while clinopyroxenes have lower Ti and Al and olivine has lower Mg (fo_{60} *cf* fo_{67}). Nepheline compositions suggest formation at ~500°C, compared to <500°C at Round Lagoon.

Inverell host nephelinite is more evolved than Round Lagoon nephelinite (Mg # 0.63 *cf* 0.66), but has a similar Na_2O/K_2O ratio (1.95 *cf* 1.96, table 6). The higher Ca and Al contents in the Inverell nephelinite may reflect its more olivine-dominated fractionation, but other magmatic differences may also apply.

An alkaline pegmatoidal clot found in a Victorian nephelinite differs from the Tasmanian examples in lacking nepheline and containing quartz, giving it a problematic relationship to its host (Ferguson 1977).

Argentina

A well studied nephelinite-pegmatoid exposure at La Madera, Córdoba (Galliski *et al.* 2004), is derived from a more primitive parental magma than for the Australian examples (Mg#0.70 *cf* 0.63–0.66). The presence of both melanocratic and leucocratic pegmatoids parallels the Inverell situation more closely than the more diverse assemblages at Round Lagoon. La Madera melanocratic assemblages are closest to Round Lagoon ijolites (RL2A), but lack sodalite, alkali feldspar and olivine. La Madera nephelines are more potassic (Ks_{30-34} *cf* Ks_{15-30}), while the Ti, Al, Na-bearing diopsides and Ti-rich magnetites overlap the Round Lagoon mineral compositions. The pyroxenes show Na and Fe^{3+} enrichment trends, but do not extend to aegirine as in the extreme Round Lagoon fractionates. Amphiboles have less Si and more Ti and K than Round Lagoon amphiboles, and are mostly katophorites rather than richterites.

Nepheline compositions in La Madera pegmatoids give more restricted T crystallisation ranges than Round Lagoon pegmatoids (750–800°C *cf* <500–980°C). Other mineral phases, not recorded in Round Lagoon assemblages, include perovskite, analcime and phillipsite-Na. The leucocratic pegmatoids at La Madera are hydrous and carbonated assemblages that indicated liquid immiscibility, a process less evident in Round Lagoon fractionation. Although injected in surface extrusions, La Madera pegmatoids provide insight into subsurface fractionation at Round Lagoon.

Round Lagoon low-P magmatic evolution

The various pegmatoids in the nephelinite demonstrate a stepped fractionation process. Separation of Mg-rich olivine, Mg-Ca-rich clinopyroxene and Mg-rich spinel during initial cooling from 1140°C depleted the magma in considerable Mg and some Ca. The greater activity of MgO over that of other oxides expands the diopside field (Deer *et al.* 1997a, Gallisky *et al.* 2004), so that wehrlitic cumulates gave way to olivine clinopyroxenite cumulates. A change, from Cr- and Mg-rich clinopyroxene to more calcic clinopyroxene, introduced two separate pyroxene components into the pegmatoid sequence. Differences in clinopyroxene phenocryst compositions related to changes in magma chamber compositions are known from phenocrysts generated below nephelinite volcanoes (e.g., at Napak volcano; Simonetti *et al.* 1996), but the precise causes that produced the two distinct Round Lagoon types (Cr- and Na-bearing augite and Ti- and Al-bearing diopside) await more detailed study. As alkalis and Fe increased in the evolving magma and temperatures dropped below 1000°C, nepheline became an important crystallising phase and the pyroxene composition moved towards aegerine-augite, rather than less stable hedenbergite (Galliski *et al.* 2004). With Al entering into nepheline, distinct changes in oxide crystallisation favoured ulvospinels over spinels.

As Si contents increased, alkali feldspar joined the other crystallising phases to form ijolites and nepheline syenites. These solidified below 850°C, as typifies lower temperature derivatives observed in the diopside-albite-nepheline experimental system (Patic *et al.* 2000). Such assemblages crystallise from host magmas similar to Round Lagoon nephelinite after removal of about 10% olivine, 20–25% diopside, 10–15% nepheline, 5–6% Ti-rich magnetite and 3–4% apatite (Wilkinson & Stolz 1983). These derivatives are limited in volume and are unlikely to deliver phonolitic eruptions at the surface. Furthermore, their mineral compositions are distinct from those in rare phonolites found in Tasmania (Everard *et al.* 2004). In those phonolites, nepheline compositions suggest higher crystallisation T, sodalite lacks a K-component, alkali feldspar includes two types, a Ba-rich and a high K-type, core clinopyroxenes are hedenbergite, amphiboles are arfvedsonite-eckermanite and hastingsite-pargasite, not richterite, and olivine is fayalite. This indicates a different genetic process. The chemical fractionation process within the Round Lagoon nephelinite may include elements of a gas-filter pressure process, where segregation of interstitial liquid takes place after 35–50% crystallisation of the host magma (Rogan *et al.* 1996).

The end fractionate in Round Lagoon nephelinite is a sanidine-diopside-amphibole assemblage, equivalent to alkaline trachyte. The overall late Na-enrichment that developed in the clinopyroxenes relative to Ca, i.e., Na/(Na+Ca) atomic ratio and Mg, i.e., cations per formula unit, ranges from Na/(Na + Ca) 0.63 → 0.91 and Mg 0.46 → 0.13. This follows the evolved pyroxene trend for Teneriffe sodalite-nepheline syenites (Wolff 1987), but at higher Mg levels. It marks an extreme Mg-rich trend (fig. 5) within late-stage alkali pyroxene trends in fractionated alkaline magmas (see Wilkinson 1977, Wolff 1987, Deer *et al.* 1997b, Ridolfi *et al.* 2006). It lies distant from trends related to carbonatitic and more saturated alkaline magma associations.

Mantle xenolith alterations

Early studies on mantle xenolith minerals from undersaturated alkaline lavas found blebs of glassy melts in some assemblages. This led to debates on their origin, whether through a mantle process or a transport decompression process (Scribano 1986, O'Connor *et al.* 1996). In Australian (Victoria) mantle xenolith studies, Yaxley *et al.* (1997) discounted both equilibrium partial melting of peridotite and migration of exotic metasomatic agents for glass generation. They favoured disequilibrium melting of *in situ* metasomatic materials, either through heating or decompressive effects. In a wide study of xenoliths, Coltorti *et al.* (2000) precluded any secondary mineral fractionations as a mechanism for forming the glasses and were able to distinguish glasses derived from mafic melt metasomatism, either sodic or potassic, or carbonatitic metasomatism. Views on whether these glasses formed at mantle depths or by lower pressure decompression during xenolith transport have adherents on both sides. Relatively high-pressure heating, with influx of various metasomatising agents was favoured for melt pockets in xenoliths from a western Hungary basalt field (Bali *et al.* 2008). In contrast, glass compositions and mineral reactions in mantle peridotite were mimicked in melting experiments at one atmosphere with a synthetic alkali host composition (Shaw & Dingwall 2008).

Round Lagoon mantle xenoliths show variable alteration in their mineralogy and textures, particularly through reaction replacements with formation of glassy melt zones. Meta-wehrlites (pl. 2H) which retain deformation zoned olivine, sieve-texture diopsides and minor Cr-bearing spinel amid extensive recrystallised glassy zones may represent spinel lherzolites, where much orthopyroxene and spinel was reacted and lost constituent elements into the recrystallising melts. The low Al contents and Al co-ordination in the sieved-textured diopsides resemble low-pressure diopside more than the diopside in pristine spinel lherzolite (table 5), suggesting decompression melting at high crustal levels.

Noticeable amounts of reaction products and glassy melt occur within Round Lagoon mantle assemblages compared with some other Tasmanian mantle xenolith suites. This may result from prolonged heating and fluid interaction of the xenoliths during their retention in a relatively slow cooling, fractionating magmatic feeder.

Round Lagoon eruptive reconstruction

The pegmatoids in this plug differ from those formed in ponded surface nephelinite lavas (e.g., at Inverell, La Madera). In the ponded situations, fractionated melts formed during fluxing in cooling horizontal bodies (Wilkinson 1977, Galliski *et al.* 2004). If such lava roofs formed above the Round Lagoon feeder, they have since been eroded away. The Tiers escarpment would be much farther east 25 million years ago, so that former related plateau lavas were possible above this feeder.

Fractionation in the plug operated in a vertical, upward-streaming setting, probably concentrating in favoured zones where enriched flux components (PO_4^{3-}, Cl^{1-}, H_2O, CO_2) inhibited nucleation and increased rates of disequilibrium crystal growth. Rare examples of vertical pegmatoid dykes occur in the plug, but the pegmatoid bodies largely resemble xenoliths in shape and size and may represent fractionation zones disrupted during ongoing magma discharge. The late, less coarse, spherical infilled pegmatoids probably mark residual fractionates that formed in a largely degassed, consolidating magma after final lava discharge.

ACKNOWLEDGEMENTS

D.F. Hendry made valuable additional EMP analyses of the minerals for this study when attached to the Department of Geology and Geophysics, University of Sydney. Facilities for EMP mineral analyses were provided by the Electron Microscope Unit, University of Sydney and the School of Earth Sciences, Macquarie University. The Australian Museum Trust provided funding for the study and the Tasmanian Geological Survey and Mineral Resources Tasmania, Hobart, provided field and laboratory support. The script was read by L.M. Barron, Research Associate, Australian Museum, Sydney. Script preparation was assisted by P. Bayliss, R. Springthorpe, Australian Museum, and F. Kelly, St Peters, Sydney. Constructive reviews of the script were made by P. Carr, School of Earth & Environmental Sciences, University of Wollongong and I. Roach, Department of Earth and Marine Sciences, Australian National University, Canberra. JLE and SMF publish with permission of the Director, Mineral Resources Tasmania.

This paper is dedicated to John F.G. Wilkinson, for his work on low-pressure fractionation of undersaturated alkaline lavas at the University of New England, Armidale, NSW.

REFERENCES

Adam, J. 1990: The geochemistry and experimental petrology of sodic alkaline basalts from Oatlands, Tasmania. *Journal of Petrology* **31**: 1201–1223.

Adam, J., Oberti, R., Cámara, F. & Green, T.H. 2007: An electron microprobe LAM-ICP-MS and single-crystal X-ray structure refinement study of the effects of pressures, melt-H_2O concentration and $f\,O_2$ on experimentally produced basaltic amphiboles. *European Journal of Mineralogy* **19**: 641–655.

Bali, E., Zanetti, A., Szabó, C., Peate, D.W. & Waight, T.E. 2008: A micro-scale investigation of melt production and extraction in the upper mantle based on silicate melt pockets in ultramafic xenoliths from the Bakony-Balaton Highland volcanic field (Western Hungary). *Contributions to Mineralogy and Petrology* **155**: 165–179.

Briggs, R.M., Rosenberg, M.D., Lange, P.J. de, Itaya, T., King, P.R. & Price, R.C. 1997: Geology and geochemistry of Gannet (Karewa) Island, Tasman Sea: a rift-related nephelinitic tuff ring. *New Zealand Journal of Geology and Geophysics* **40**: 263–273.

Bultitude, R.J. & Green, D.H. 1971: Experimental study of crystal-liquid relationships at high pressures in olivine nephelinite and basanite compositions. *Journal of Petrology* **12**: 121–147.

Cebeira, J.M. 1990: PX: A program for pyroxene classification and calculation. *American Mineralogist* **75**: 1426–1427.

Chazot, G., Menzies, M.A. & Harte, B. 1996: Determination of partition coefficients between apatite, clinopyroxene, amphibole and melt in natural spinel lherzolites from Yemen: implications of wet melting in the lithospheric mantle. *Geochimica et Cosmochimica Acta* **60**: 423–427.

Coltorti, M., Beccaluva, L., Bonadiman, C., Salvini, L. & Siena, F. 2000: Glasses in mantle xenoliths as geochemical indicators of metsomatic agents. *Earth and Planetary Science Letters* **183**: 303–320.

Deer, W.A., Howie, R.A. & Zussman, J. 1982: Olivine. *In Rock-forming Minerals, Volume 1A. Second Edition, Orthosilicates,* Longman, London: 3–336.

Deer, W.A., Howie, R.A. & Zussman, J. 1997a: Diopside-Hedenbergite. *Rock-forming Minerals, Volume 2B, Second Edition, Double-chain Silicates.* The Geological Society, London: 764 pp.

Deer, W.A., Howie, R.A. & Zussman, J. 1997b: Aegirine. *Rock-forming Minerals, Volume 2B, Second Edition, Double-chain Silicates.* The Geological Society, London: 482–519.

Direen, N.G. & Leaman, D.E. 1997: Geophysical modelling of structure and tectonostratigraphic history of the Longford Basin, northern Tasmania. *Exploration Geophysics* **28**: 29–33.

Edgar, A.D. 1984: Chemistry, occurrence and paragenesis of feldspathoids: a review. *In* Brown, W.L. (ed.): *Feldspars and Feldspathoids: Structures, Properties and Occurences.* D. Reidal, Dorrecht, The Netherlands: 501–532.

Eggins, S.M., Rudnick, R.L. & McDonough, W.F. 1998: The composition of peridotites and their minerals: a laser-ablation ICP-Ms study. *Earth and Planetary Sciences Letters* **154**: 53–71.

Everard, J.L. 2001: Inclusions of high pressure origin in Tasmanian Cenozoic basalts: a catalogue of localities. *Tasmanian Geological Survey Record* 2001/09.

Everard, J.L., Sutherland F.L. & Zwingmann, H. 2004: A Cretaceous phonolite dyke from the Tomahawk River, Northeast Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **138**: 11–33.

Ferguson, A.K. 1977: A note on a ramsayite-bearing pegmatoidal clot in a mela-nephelinite from the Older Volcanics near Bacchus Marsh, Victoria. *Journal of the Geological Society of Australia* **24**: 491–494.

Fodor, R.V., Bauer, G.R. & Keil, K. 1982: Ultramafic inclusions and megacrystals in olivine nephelinite, Aitutaki Island, Cook Islands. *New Zealand Journal of Geology and Geophysics* **25**: 67–76.

Forsyth, S.M. 1989: Geological Survey Explanatory Report. Geological Atlas 1:50 000 Series Sheet 61 (8313 N). Interlaken. *Tasmanian Department of Mines.*

Galliski, M.A., Lira, R. & Dorais, M.J. 2004: Low pressure differentiation of melanephelinitic magma and the origin of ijolitic pegmatites at La Madera, Córboda, Argentina. *Canadian Mineralogist* **42**: 1799–1823.

Green, D.H. & Falloon, T.J. 1998: Pyrolite: A Ringwood concept and its current expression. *In* Jackson, I. (ed.): *The Earth's Mantle. Composition, Structure and Evolution.* Cambridge University Press, Cambridge: 311–378.

Hamilton, D.L. 1961: Nephelines as crystallisation temperature indicators. *Journal of Geology* **69**: 321–329.

Hutchison, C.S. 1974: *Laboratory Handbook of Petrographic Techniques.* John Wiley & Sons, New York: 527 pp.

Johnson, R.W. (ed.) 1989: *Intraplate Volcanism in Eastern Australia and New Zealand.* Cambridge University Press, Cambridge: 408 pp.

Kretz, R. 1983: Symbols for rock-forming minerals. *American Mineralogist* **68**: 277–279.

Leake, B.E. & contributers 1997: Nomenclature of amphiboles: report of the sub-committee on Amphiboles of the International Mineralogical Association, Commission of New Minerals and Mineral Names. *Canadian Mineralogist* **35**: 219–246.

Le Maitre, R.W. (ed.) 2002: *Igneous Rocks: A Classification and Glossary of Terms. Second Edition,* Cambridge University Press, Cambridge: 252 pp.

London, D. 2008: *Pegmatites.* Mineralogical Association of Canada Special Publication 10, Quebec: 368 pp.

McDonough, W.F., McCulloch, M.J. & Sun, S-S. 1985: Isotopic and geochemical systematics in Tertiary-Recent basalts from south eastern Australia and implications for the evaluation of the sub-continental lithosphere. *Geochimica et Cosmochimicia Acta* **49**: 2051–2067.

Mason, D.R. 1985: Polybaric crystallisation of clinopyroxene in ankaramites of the Barrington Tops Tertiary Volcanic Field. *In* Sutherland, F.L., Franklin, B.J. & Waltho, A.E. (eds): *Volcanism in eastern Australia. Geological Society of Australia, New South Wales Division, Special Publication* **1**: 84–105.

Morimoto, N. 1988: Nomenclature of pyroxenes. *Mineralogical Magazine* **52**: 535–550.

O'Connor, T.K., Edgar, A.D. & Lloyd, F.E. 1996: Origin of glass in Quaternary mantle xenoliths from Meerfeldermaar, West Eifel, Germany: implications for enrichment in the lithospheric mantle. *Canadian Mineralogist* **34**: 187–200.

Patic, J.K., Arima, M. & Gupta A.K. 2000: Experimental study of the system diopside-albite-nepheline at P (H_2O) = P(Total) = 2 and 10Kbar and at P(Total) = 28Kbar. *Canadian Mineralogist* **38**: 1177–1191.

Preston, R.J., Hole, M.J. & Still, J. 2000: The occurrences of Zr-bearing amphiboles and their relationships with the pyroxenes and biotites in the teschenite and nepheline syenites of a differentiated dolerite boss, Islay, NW Scotland. *Mineralogical Magazine* **64**: 459–468.

Rawlinson, N., Houseman, G.A., Collins, C.D.N. & Drummond, B.J. 2001: New evidence of Tasmania's tectonic history from a novel seismic experiment. *Geophysical Research Letters* **28**: 3337–3340.

Ridolfi, F., Renzulli, A., Macdonald, R. & Upton, B.G.J. 2006: Peralkaline syenite autoliths from Kilombe volcano, Kenya Rift Valley: Evidence for subvolcanic interaction with carbonatitic fluids. *Lithos* **91**: 373–392.

Rogan, W., Blake, S. & Smith, I. 1996: In situ chemical fractionation in thin basaltic lava flows: examples from the Auckland volcanic field, New Zealand and a general

physical model. *Journal of Volcanology and Geothermal Research* **74**: 89–99.

Scribano, V. 1986: The harzburgite xenoliths in a Quaternary basanitoid lava near Scordia (Hyblean Plateau, Sicily). *Rendictoni Società Italiana di Mineralogia e Petrologia* **41**(2): 245–255.

Shaw, C.S.J. & Dingwell, D.B. 2008: Experimental peridotite-melt reaction at one atmosphere: a textural and chemical study. *Contributions to Mineralogy and Petrology* **155**: 199–214.

Simonetti, A., Shore, M. & Bell, K. 1996: Diopside phenocrysts from nephelinitic lavas, Napak volcano, eastern Uganda: Evidence for magma mixing. *Canadian Mineralogist* **34**: 411–421.

Smith, I.E.M., Blake, S., Wilson, C.J.N. & Houghton, B.F. 2008: Deep seated fractionation during the rise of a small volume basalt magma batch: Crater Hill, Auckland, New Zealand. *Contributions to Mineralogy and Petrology* **155**: 511–527.

Spera, F.J. 1984: Carbon dioxide in petrogenesis: 111. Role of volatiles in the ascent of alkaline magma with special reference to xenolith-bearing mafic lavas. *Contributions to Mineralogy and Petrology* **88**: 217–232.

Sun, S-S. & McDonough, W.F. 1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. *In* Saunders, A.D. & Norry, M.J. (eds): *Magnetism in the Ocean Basins. Geological Society Special Publication* No. **42**: 313–345.

Sutherland, F.L. 1974: High-pressure inclusions in tholeiitic basalt and the range of lherzolite-bearing magmas in the Tasmanian volcanic province. *Earth and Planetary Science Letters* **24**: 317–232.

Sutherland, F.L. 1989: Cainozoic volcanic rocks. *In* Forsyth, S.M. (Compiler): Geological Survey Explanatory Report. Geological Atlas 1:50 000 Series Sheet 61 (8313N). Interlaken. *Tasmanian Department of Mines*: 48–60.

Sutherland. F.L. & Hollis, J.D. 1982: Mantle-lower crust petrology from inclusions in basaltic rocks in eastern Australia – an outline. *Journal of Volcanology and Geothermal Research* **14**: 1–29.

Sutherland F.L. and contributors 1989: Tertiary volcanism, Tertiary basaltic magmas and the Tasmanian lithosphere. *In* Burrett, C.F. & Martin, E.L. (eds): Geology and Mineral Resources of Tasmania. *Geological Society of Australia Special Publication* **15**: 383–398.

Sutherland, F.L., Graham, I.T., Everard, J.L., Forsyth, S.M. & Zwingmann, H. 2004: Cenozoic basalts, Tasmania: Landscapes, exposures, ages, petrology, geochemistry, entrainments and petrogenesis. *Geological Society of Australia* Field Guide A5, Sydney: 58 pp.

Sutherland, F.L., Hendry, D.F., Barron, B.J., Matthews, W.L. & Hollis, J.D. 1996: An unusual Tasmanian Tertiary basalt sequence near Boat Harbour, Northwest Tasmania. *Records of the Australian Museum* **48**: 131–161.

Sutherland, F.L., Raynor, L.R. & Pogson, R.E. 2005: Table Cape xenolithic suite, northwest Tasmania: Mineralogy and implications for crust-mantle lithology and Miocene geotherms in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **139**: 7–22.

Ulrych, J., Lloyd, F.E., Balogh, K., Hegner, E., Langrová, A., Lang, M., Novák, J.K. & Randa, Z. 2005: Petrogenesis of alkali pyroxenite and ijolite xenoliths from the Tertiary Loučná-Oberweisenthal Volcanic Centre, Bohemian Massif in the light of new mineralogical, geochemical, and isotopic data. *Neues Jahrbuch für Mineralogie-Abhandlungen* **182**: 57–59.

Ulrych, J., Pivec, E., Lang, M. & Lloyd, F.E. 2000: Ijolite segregations in melilite nephelinite of Podhorni vrch volcano, Western Bohemia. *Neues Jahrbuch für Mineralogie-Abhandlungen* **175**: 317–348.

Wass, S.Y. 1979: Multiple origins of clinopyroxenes in alkali basaltic rocks. *Lithos* **12**: 115–132.

Wells, P.R.A. 1977: Pyroxene thermometry in simple and complex systems. *Contributions to Mineralogy and Petrology* **62**: 129–130.

Wilkinson, J.F.G. 1977: Petrogenetic aspects of some alkali volcanic rocks. *Journal & Proceedings of the Royal Society of New South Wales* **110**: 117–138.

Wilkinson, J.F.G. & Stolz, A.J. 1983: Low pressure-fractionation of strongly undersaturated alkaline ultrabasic magma: the olivine-melilite-nephelinite at Moiliili, Oahu, Hawaii. *Contributions to Mineralogy and Petrology* **83**: 363–374.

Wittke, J.H. & Holm, R.F. 1996: The association basanitic nephelinite-feldspar ijolite-nepheline monzosyenite at House Mountain volcano, north-central Arizona. *Canadian Mineralogist* **34**: 221–240.

Wolff, J.A. 1987: Crystallisation of nepheline syenite in a subvolcanic magma system: Teneriffe, Canary Islands. *Lithos* **20**: 207–223.

Woodland, A.B. & Jugo, P.J. 2007: A complex magmatic system beneath the Devès volcanic field, Massif Central, France: evidence from clinopyroxene megacrysts. *Contributions to Mineralogy and Petrology* **153**: 719–731.

Yavuz, F. 1996: Amphcal: A quick basic program for determining the amphibole name from electron microprobe analyses using the IMA rules. *Computers and Geosciences* **22**: 101–107.

Yaxley, G.M., Kamenestky, V., Gran, D.H. & Falloon, T.J. 1997. Glasses in mantle xenoliths from western Victoria, Australia and their relevance to mantle processes. *Earth and Planetary Science Letters* **148**: 433–466.

Zhou, J. & Li, X. 2006: GeoPlot: An Excel VBA program for geochemical data plotting. *Computers and Geosciences* **32**: 554–560.

(accepted 7 October 2008)

A NEW SPECIES OF FRESHWATER SPONGE (PORIFERA:SPONGILLIDAE) OF THE GENUS *RADIOSPONGILLA* FROM LAKE PEDDER IN TASMANIA

by Andrew W. Osborn, G. Nigel R. Forteath and John Stanisic

(with three plates)

Osborn A.W., Forteath, G.N.R. & Stanisic, J. 2008 (28:xi): A new species of freshwater sponge (Porifera:Spongillidae) of the genus *Radiospongilla* from Lake Pedder in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 39–44. ISSN 0080-4703. Queen Victoria Museum & Art Gallery, 2 Wellington Street, Launceston, Tasmania 7250, Australia (AWO, GNRF*), Queensland Museum, PO Box 3300, South Brisbane, Queensland 4101, Australia (JS). *Author for correspondence.

Lake Pedder is the home of a number of relictual organisms. One of those, a new species of freshwater sponge of the genus *Radiospongilla*, is described herein. *Radiospongilla pedderensis* sp. nov. occurs throughout most of the lake and often is found in very large numbers in many bays. *Radiospongilla* is widely distributed in tropical and sub-tropical regions of all continents. The pneumatic layer of the gemmule contains numerous abnormal gemmoscleres a condition probably caused by the chemistry of the lake. The morphology and dimensions of the megascleres, gemmoscleres and aberrant gemmoscleres, as well as the location, structure and size of gemmules, are provided for *R. pedderensis*. The sponge is a bright green colour due to intracellular zoochlorellae. Their presence in local members of *Radiospongilla* has been the subject of considerable speculation but herein they are illustrated for the first time in an Australian species.

Key Words: Spongillidae, *Radiospongilla pedderensis* sp. nov., freshwater sponge, zoochlorellae, Lake Pedder, Tasmania, Australia.

INTRODUCTION

Lake Pedder is an oligotrophic body of water that is managed as a reservoir. Originally Lake Pedder covered only 5% of its present shoreline. Dams were completed in 1972 at strategic locations around the perimeter of what was to become the new Lake Pedder and the lake expanded dramatically. It took two years for it to fill to capacity. Thus, the enlarged lake has been in existence for 34 years. Many lengthy fetches are now present: one in excess of 21 km.

Lake Pedder is located in a region of folded Precambrian quartzites while the Serpentine River Valley, now part of the lake, cut through softer phyllites and schist (Kiernan 2001). Soils in the bed of the present lake and those which surround it are typically organic regolith. According to Pemberton (2001) these soils are thought to be muck peat. They vary in depth from as little as 1–10 cm to deposits that are up to 2 m in depth (Brown 1999).

At full supply, Lake Pedder contains 3.3 km^3 of fresh water, has a surface area of 235 km^2 with a shoreline that is equal to 10% of the coastline of the state of Tasmania and is 308.46 m above sea level. It is situated wholly within Tasmania's Southwest National Park. For environmental reasons, Tasmanian state legislation stipulates that the surface level of Lake Pedder cannot legally deviate outside the range of 306.93–308.46 m above sea level. As a direct result, Lake Pedder provides a large, remarkably stable environment for cool-temperate aquatic organisms.

An undescribed freshwater sponge of the genus *Radiospongilla* occurs commonly throughout many habitats in Lake Pedder, the shores of which range from Northings 5264680 and 5235000 and Eastings 416550 and 448280 (GDA 94). Previously no species of *Radiospongilla* had been recorded from Tasmania.

According to Williams (1980), the only spongillid to have been recorded from Tasmania is *Heterorotula nigra* (Lendenfeld, 1887) Similarly, Gooderham & Tsyrlin (2002) state that a single spongillid has been recorded from Tasmania, but do not name that species. According to Racek (1969), two spongillid species have been collected from Tasmania. However, both these species were originally named from specimens that were collected on the mainland by Lendenfeld (1887) (*Heterorotula nigra*) and by Weltner (1895, 1900, 1910) (*H. multidentata* (Weltner, 1900)). The undescribed species cannot be attributed to either of the above taxa and thus is the third freshwater sponge known to exist in Tasmania. Flynn (1923) recorded an unknown spongillid from a tributary of the Inglis River in the northwest of Tasmania near Wynyard. Unfortunately he did not provide details upon which his classification of *Ephydatia multiformis* Weltner, 1910 was based. Flynn refers the reader to Weltner (1900) for verification, however; but that article contains no reference to *E. multiformis*. Rather it concentrates on *E. multidentata* and it would appear that Flynn was referring to *E. multidentata*. Racek (1969) concluded that it was not possible to ascribe the sponge discussed therein to its correct genus and species. We concur with that assessment.

The present paper reports the first record of the presence of a species of radiospongillid in Tasmania and concurrently provides the first real evidence of zoochlorellae in any species of radiospongillid in Australia. In the new species, described here, the majority of gemmoscleres are largely abnormal, a condition ascribed to a silica imbalance in the lake's water chemistry (Poirrier *et al.* 1987).

SYSTEMATICS

Spongillidae Gray, 1867
Radiospongilla Penney & Racek, 1968
Radiospongilla pedderenisis sp. nov.

Type material

Type material deposited in the Queen Victoria Museum & Art Gallery, Launceston, Tasmania, Australia (registration

no.: QVM:21:4056). Histological sections of gemmules and histological slides containing megascleres, gemmoscleres and abnormal gemmoscleres deposited in the Queen Victoria Museum & Art Gallery: QVM:21:4057–60.

Etymology
For the type locality.

Description
Radiospongilla pedderensis forms relatively shallow encrustations, albeit often very expansive ones which, when they are mature, typically encompass the entire circumference of extended sections (≥0.8 m in length) of flooded tree trunks and branches. In relatively calm areas the sponge can be found growing attached to the surfaces of rocks. In addition to encrustations, *R. pedderensis* (pl. 1) often produces finger-like projections from the encrustations described previously. The surface of *R. pedderensis* is irregular and, because the ends of spicules project through the body surface, is hispid. Oscula are small, but can be seen with the naked eye. *R. pedderensis* forms an irregular network of spicules, which are held together by relatively large amounts of spongin. Living specimens of *R. pedderensis* have a compact texture and are firm when touched.

Megascleres are feebly curved to almost straight, fusiform amphioxea. The surface of a megasclere is sparsely covered with microspines that are both curved and sharp. Details of these microspines are visible only under high-power light microscopy or transmission electron microscopy (pls 2A,B). Megascleres range in length from 195–242 μm (212 μm where n = 25). These scleres range in width from 6.5–8.8 μm ($\bar{x}$ = 7.2 μm where n = 13).

Normal gemmoscleres are few in number and are polymorphic. Most commonly, the shaft of each individual microsclere of *R. pedderensis* is cylindrical and spiny. Some of these scleres are straight while others are slightly curved. The ends of gemmoscleres in *R. pedderensis* are (i) amphistrongyla, (ii) amphioxea, or (iii) one end may be blunt while the other is sharp. The gemmoscleres of *R. pedderensis* typically terminate with at least one end in the form of a coronet of very small, recurved spines. Behind the coronet, gemmoscleres usually bear a second ring of larger recurved hooks, which arise from the shaft of the sclere once it obtains full diameter (pl. 2C). Variations include lack of coronet and/or the presence of one or more straight macrospines which often give rise to an asymmetrical gemmosclere (pl. 2D). Gemmoscleres range in length from 100–136.4 μm ($\bar{x}$ = 121.2 μm, where n = 18) and in width from 3.1–5.0 μm ($\bar{x}$ = 4.4 μm, where n = 21).

Abnormal gemmoscleres are straight to feebly-curved spicules. They normally possess one terminal, but not uncommonly two and rarely three widely-separated bulbous swellings (pls 2E, F). Where two or more swellings occur on a single sclere, these expansions on the spicule are cylindrical and lanceolate. Abnormal gemmoscleres are extremely plentiful in the pneumatic layer of a gemmule. These scleres range in length from 53.0–76.6 μm ($\bar{x}$ = 68.3 μm where n = 12) and in width from 1.4–2.2 μm ($\bar{x}$ = 1.7 μm where n = 12).

Gemmules are spherical and range in diameter from 480–630 μm ($\bar{x}$ = 528 μm where n = 17). An effective protective covering surrounds each gemmule (pl. 3A). It consists of abundant megascleres and a smaller number of gemmoscleres. Some megascleres penetrate the pneumatic

PLATE 1
A specimen of Radiospongilla pedderensis *in which finger-like projections are seen to be arising from and along the base of the encrusted sponge.*

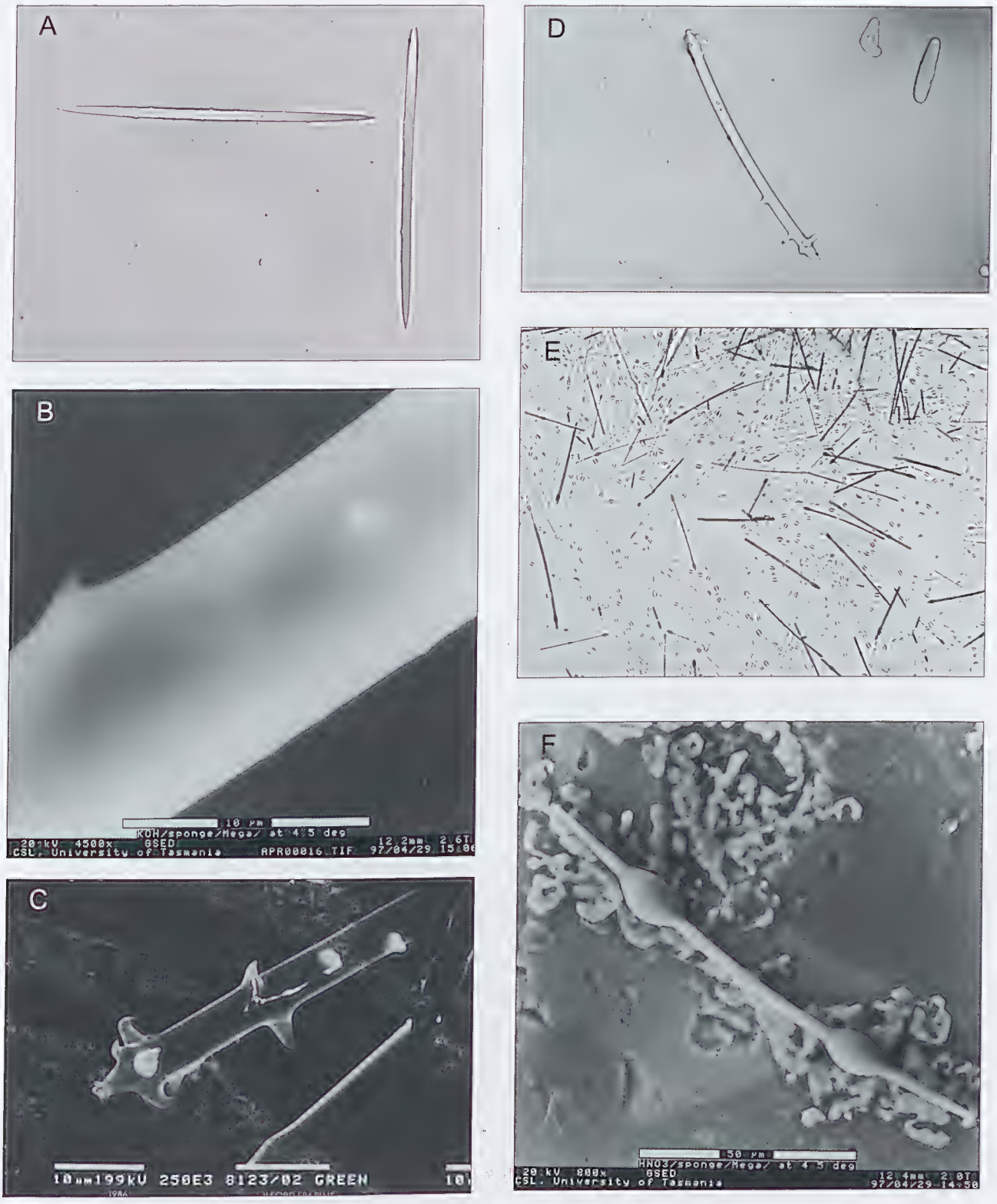


PLATE 2

(A) A megasclere from Radiospongilla pedderensis *(length 226 µm) showing the general appearance of these fusiform, amphioxea scleres. Note that the surface of the megasclere is sparsely covered with microspines. (B) Transmission electron micrograph of a megasclere from* R. pedderensis, *showing curved microspines (single scale bar = 10 µm). (C) Transmission electron micrograph of the terminal coronet of recurved spines on a true gemmosclere from* R. pedderensis *(single scale bar = 10 µm). (D) An abnormal gemmosclere from* R. pedderensis *(length 207.9 µm) under high-power light microscopy in which straight macrospines are present. (E) Abnormal gemmoscleres from* R. pedderensis *under light microscopy. (These range in length from 53.0–76.6 µm). (F) Transmission electron micrograph of an abnormal gemmosclere from* R. pedderensis *with two lanceolate swellings. (single scale bar = 50 µm).*

layer of a gemmule. The porus tube of the foramen is simple and globular in shape. The apex of the foramen protrudes above the surface of the gemmular membrane where it looks like a nipple (pl. 3B); however, this protrusion (i.e., the porus tube of the foramen) lies in a deep, conical depression. The pneumatic layer of a gemmule is filled in part with air spaces (pl. 3C).

Colour

Deep green (photic zone) to greyish-white (aphotic zone).

Comparison with other species

Since Penney & Racek (1968) erected *Radiospongilla*, there have been three new species which have been ascribed to this genus in Australia and overseas, namely: *Radiospongilla ornata* from Argentina (Bonetto & Ezcurro de Drago 1970; subsequently transferred to *Anheteromeyenia* by Volkmer-Ribeiro 1996), *R. streptasteriformis* from the Northern Territory, Australia (Stanisic 1979), and *R. amazoniensis* from Brazil (Volkmer-Ribeiro & Maciel 1983)). *R. pedderensis* is clearly differentiated from *R. streptasteriformis* and *R. amazoniensis*. *R. streptasteriformis* has megascleres which are spinose, fusiform amphioxea while those of *R. amazoniensis* are stout amphistrongyla. This contrasts markedly to the megascleres in *R. pedderensis* which are more delicate, fusiform amphioxea. Most significantly the true gemmoscleres of *R. pedderensis* differ markedly from those of other local *Radiospongilla* spp. They are most similar to those of *R. sceptroides* but differ by the having a more incipiently spined shaft and overall greater length.

DISCUSSION

Radiospongilla pedderensis is a very common and widely-distributed spongillid in Lake Pedder in the southwest of Tasmania. The species forms moderately firm, large encrustations on flooded timber and, when specimens are protected from meaningful wave action, thinner sponges may grow on rock surfaces. Also, in calmer waters, or at greater depths, finger-like projections often grow from the surface of *R. pedderensis*.

At present the known distribution of *R. pedderensis* is within Lake Pedder, where it is widespread throughout its extensive shores to depths of at least 10 m. The species may live at even greater depths, but sampling in those regions has yet to be undertaken. However, this species has not been observed to grow at sites where meaningful sedimentation would be deposited on their surfaces, or in sites that are exposed to heavy wave action. During calm and sunny conditions, an observer wearing polaroid sunglasses, can see very large numbers of *R. pedderensis* growing on the submerged trunks and branches of flooded trees and shrubs in the shallow regions of Starfish Inlet (GDA 94) E. 418563 and N. 5254030.

When they live in the photic zone, specimens of *R. pedderensis* are deep green in colour. However, because the water in Lake Pedder is heavily tanninised, the depth of the photic zone is partially constrained. Specimens of *R. pedderensis* which grow beneath the photic zone are greyish-white in appearance.

The verdant coloration of *R. pedderensis* is caused by the presence of intracellular zoochlorellae that live within the sponge cells, specifically the archaeocytes (pls 3D, E). The ellipsoidal shape of these algae, together with the presence of a cup-shaped chloroplast and a pyrenoid all suggest that they belong to the Chlorococcale group. Racek (1969) suggested that intracellular zoochlorellae were responsible for the green colour in several Australian radiospongillids; however, herein we provide the first documented evidence of such an association in a local species. Zoochlorellae have been well documented in overseas freshwater sponges (e.g., Gaino *et al.* 2003).

Racek (1969) also speculates that these zoochlorellae are in a symbiotic relationship with the sponge, but while this relationship has been proven experimentally in overseas freshwater sponges (Wilkinson 1980), similar studies have yet to be conducted on the local species.

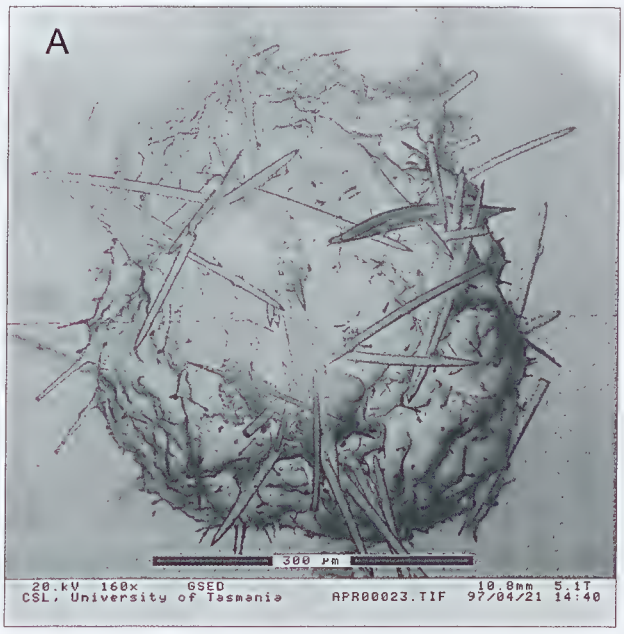
At three main locations within Lake Pedder a newly described species of the sponge-fly genus *Sisyra* (Smithers *et al.* 2008) occurs. Aquatic larvae of these small lacewings (Neuroptera: Sisyridae) are found living upon *R. pedderensis*. Sponge-flies are specialised predators of freshwater sponges and they are almost invariably found only with their prey (New 2004).

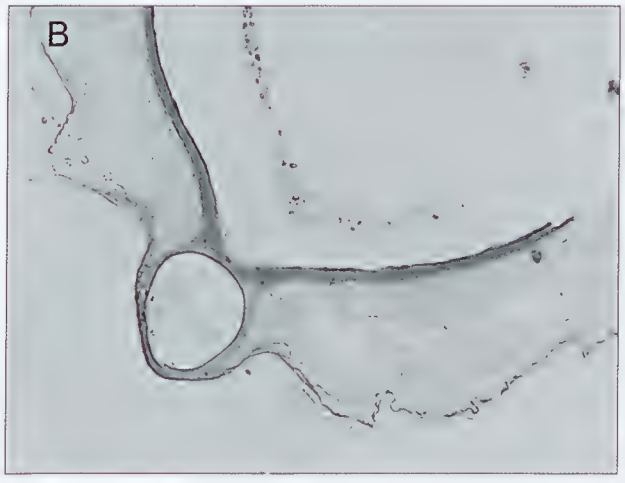
When this species is collected in peak summer (i.e., January) numerous gemmules are often present. According to Penney & Racek (1968) large numbers of gemmules are to be found in maturing sponges within *Radiospongilla*. When a gemmule matures in *R. pedderensis* it becomes golden-yellow in colour. In *R. pedderensis* gemmules are to be found throughout mature sponge tissue and are relatively large when compared with those of most other Australian congeners.

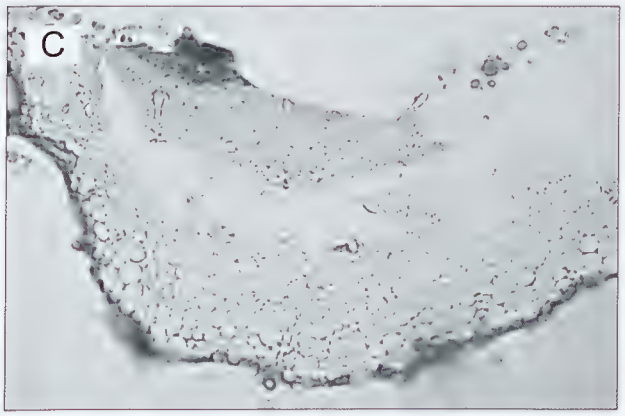
Analyses of water samples from 1999 to date reveal that the temperature of Lake Pedder ranges between 5.9 and 20.5°C. The pH range recorded in Lake Pedder is from 5.6 to 6.8 while conductivity, measured at 25°C in µs, varies between 30.4 and 46.1 over the same period. Finally, total nitrogen in Lake Pedder ranged up to a maximum of 193.94 µg/l. Paduano & Fell (1997) recorded water quality parameters for lakes in which another species of radiospongillid, *R. crateriformis*, grows in the state of Connecticut in the northeastern United States. Their data from those lakes reveal that pH varies between 6.8 and 7.1 while conductivity (again measured at 25°C in µs) ranges from 39 to 58 and total nitrogen ranged up to a maximum of 312 µg/l. Temperature readings were not provided. Although some differences are apparent, these two radiospongillids appear to grow under very similar conditions with reference to these parameters of water quality.

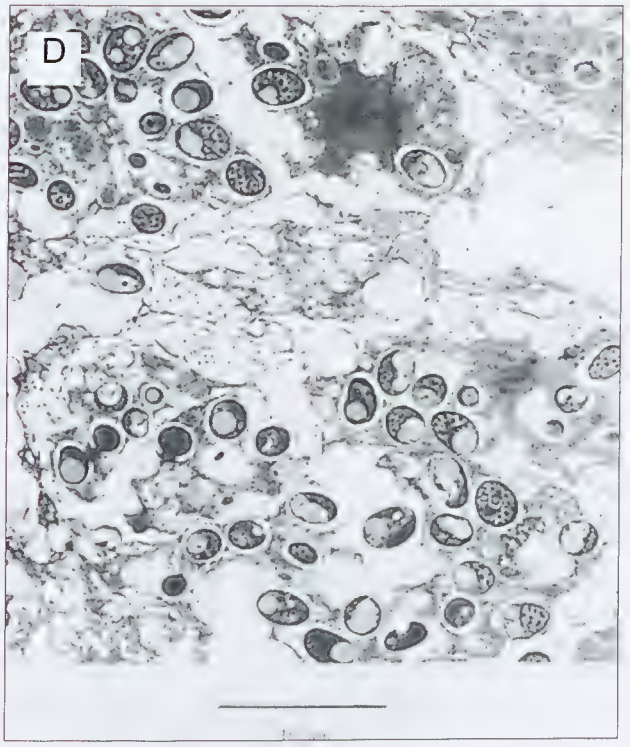
Expanded key to the Australian species of *Radiospongilla*

1. Gemmoscleres forming a double layer, the inner radially, the outer irregularly arranged; megascleres broadly fusiform ..... *R. philippinensis* (Annandale)
   Gemmoscleres forming a single layer of radial arrangement; megascleres slender fusiform 2
2(1) Gemmular porus tube surrounded by a conical depression; immature gemmoscleres not abundant in symplasm or dermal membrane 3
   Gemmular porus tube surrounded by 3–4 mammiform aspiculous enlargements of the pneumatic coat; immature gemmoscleres usually abundant in symplasm and dermal membrane ... . *R. hemephydatia* (Annandale)
3(2) Megascleres armed with conspicuous spines 4
   Megascleres with microspines 5









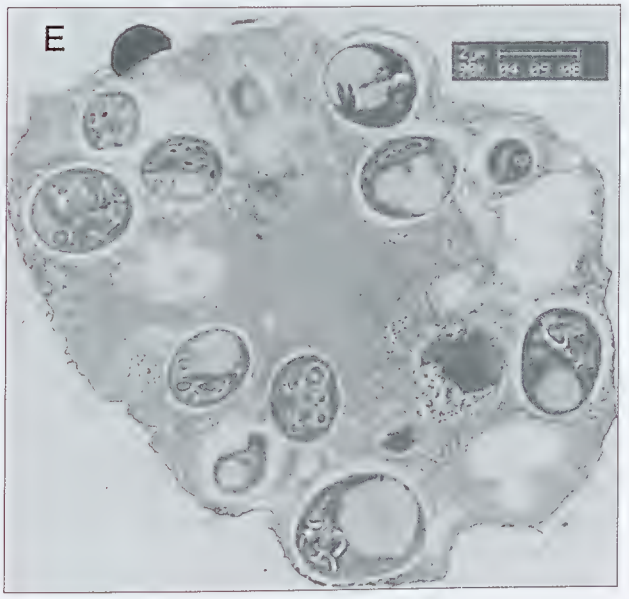


PLATE 3

(A) Transmission electron micrograph of the protective covering surrounding a gemmule from Radiospongilla pedderensis *(single scale bar = 300 µm). (B) A transverse section of a gemmule from* R. pedderensis *under light microscopy depicting the single, simple, globular, gemmular porus tube (length 70µm) surrounded on the external surface by a deep conical depression when viewed from above. (C) The pneumatic layer (width 55 µm) of a* R. pedderensis *gemmule under light microscopy, which reveals air spaces. It is in this layer that the abnormal gemmoscleres are found. (D) Transmission electron micrograph of zoochlorellae within the general symplasm of* R. pedderensis. *(Scale bar =10µm) (E) Transmission electron micrograph of zoochlorellae within an individual archaeocyte of* R. pedderensis. *(Scale bar = 2µm)*

4(3) Tips of megascleres free from spines; gemmoscleres typically amphioxea ..... *R. synoica* Racek
Tips of megascleres armed with conspicuous aggregations of larger spines; gemmoscleres typically amphistrongyla ..... *R. multispinifera* (Gee)

5(3) Gemmules comparatively small (310–380 µm) and gemmoscleres typically amphioxea .... *R. hispidula* Racek
Gemmules comparatively large (420–630 µm) and gemmoscleres typically amphistrongyla 6

6(5) Gemmoscleres armed with numerous acute spines towards the extremities of the scleres .... *R. sceptroides* (Haswell)
Gemmoscleres normally amphistrongyla with few spines, sometimes with a terminal spine in continuation of the main shaft thus giving the appearance of amphioxea..... .....*R. pedderensis* sp. nov.

ACKNOWLEDGEMENTS

We thank Mr David Seaton, Manager of the Launceston General Hospital's histopathology laboratory, for access to some of its facilities as well as for arranging to undertake histological sections of *R. pedderensis* gemmules for us. We also thank Dr J. Purser, Deputy Head of the School of Aquaculture at the University of Tasmania, for access to and assistance with photomicroscopy facilities and Associate Professor D. McWilliam of the School of Chemistry at the University of Tasmania for access to a chemistry laboratory which enabled us to digest *R. pedderensis* gemmules for analyses of scleres under light microscopy. Thanks also to the Central Science Laboratory of the University of Tasmania for conducting electron microscopy on (i) various types of scleres as well as (ii) gemmules from *R. pedderensis*. We greatly appreciate the work of Mrs G. Nash, electron microscopist within the Australian Antarctic Division, for the electron- micrographs that reveal the presence of zoochlorellae. With reference to field studies on Lake Pedder, we thank Messrs J. Ford and C. Livingston for (i) valuable coxswain assistance; (ii) the precise geographic location of the field sites – J.F.; and (iii) water chemistry data for Lake Pedder – C.L. The research was made possible by grants from Hydro Tasmania and the W.D. Booth Charitable Trust. Finally, support has also been forthcoming from the Queen Victoria Museum & Art Gallery.

REFERENCES

Bonetto, A.A. & Ezcurra de Drago, I. 1970: Esponjas de los afluentes del alto Paraná en la provincia de Misiones. Acta Zoologica Lilloana **27**: 37–61.

Brown, M.J. 1999: Buttongrass moorlands. *In* Reid, J.B., Hill, R.S., Brown, M.J. & Hovenden, M.J. (eds): *Vegetation of Tasmania. Flora of Australia Supplementary Series* **8**: 286–303. ABRS, Canberra.

Flynn, T.T. 1923: On a fresh-water sponge from Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 1922: 58–59. [Note: The date quoted for this article has invariably been given as 1922; however, the actual publication date is 26 February 1923].

Gaino, E., Rebora, M., Corallini, C. & Lancioni, T. 2003: The life-cycle of the sponge *Ephydatia fluviatilis* (L.) living on the reed *Phragmites australis* in an artificially regulated lake. *Hydrobiologia* **495**:127–142.

Gooderham, J. & Tsyrlin, E. 2002: *The Waterbug Book: A Guide to the Freshwater Macroinvertebrates of Temperate Australia.* CSIRO Publishing, Collingwood, Victoria: 232 pp.

Kiernan, K. 2001: The geomorphology and geoconservation significance of Lake Pedder: *In* Sharples, C. (ed.): *Values and Restoration. Occasional Paper* **27**: Centre for Environmental Studies, University of Tasmania: 13–50.

Lendenfeld, R. von 1887: Die Süsswasser-Coelenteraten Australiens. *Zoologische Jahrbücher, Abteilung für Systematik, Geographie und Biologie der Thiere* **2**: 87–108.

New, T.R. 2004: *Introduction to the Systematics and Biology of Australian Aquatic Neuroptera.* Cooperative Research Centre for Freshwater Ecology: Identification & Ecology Guide No. 49: 33 pp.

Paduano, G.M. & Fell, P.E. 1997: Spatial and temporal distribution of freshwater sponges in Connecticut lakes based upon analysis of siliceous spicules in dated sediment cores. *Hydrobiologia* **350**: 105–121.

Pemberton, M. 2001: Soils in the Lake Pedder area. *In* Sharples, C. (ed.): *Values and Restoration.* Occasional Paper 27: Centre for Environmental Studies, University of Tasmania: 61–65.

Penney, J.T. & Racek, A.A. 1968: Comprehensive revision of a worldwide collection of freshwater sponges (Porifera: Spongillidae). *Bulletin of the United States National Museum Number* 272, Smithsonian Institution Press, Washington D.C.: 184 pp.

Poirrier, M.A., Martin, P.S. & Baerwald, R.J. 1987: Comparative morphology of microsclere structure in *Spongilla alba, S. cenota* and *S. lacustris* (Porifera: Spongillidae). *Transactions of the American Microscopical Society Inc.* **106**(4): 302–310.

Racek, A.A. 1969: The freshwater sponges of Australia (Porifera: Spongillidae). *Australian Journal of Marine and Freshwater Research* **20**: 267–310.

Smithers, C.N., Forteath, G.N.R. & Osborn, A.W. 2008: A new species of *Sisyra* (Insecta: Neuroptera: Sisyridae) from Lake Pedder, Tasmania. *Australian Journal of Entomology* **47**: 77–79.

Stanisic, J. 1979: Freshwater sponges from the Northern Territory (Porifera; Spongillidae). *Proceedings of the Linnaean Society of New South Wales* **103**(2): 123–130.

Volkmer-Ribeiro, C. 1996: *Acanthodiscus* new genus and *Anheteromeyenia* redefined (Porifera, Spongillidae). *Iheringia, Série Zoologia, Porto Alegre* **81**: 31–43.

Volkmer-Ribeiro, C. & Maciel, S.B. 1983: New freshwater sponges from Amazonian waters. *Amazoniana Kiel* **8**(2): 255–264.

Weltner, W. 1895: Spongillidenstudien III. Katalog und Verbreitung der bekannten Süsswasserschwämme. *Archiv für Naturgeschichte* **61**(1): 114–144.

Weltner, W. 1900: Süsswasser-Schwämme *In* Semon R. (ed.): Zoologische Forschungsreisen in Australien und dem Malayischen Archipel. *Denkschriften der medicinisch-naturwissenschaftlicher Gesellschaft zu Jena* **8**(5): 519–523.

Weltner, W. 1910: Spongillidae. *In* Michaelsen, W. & Hartmeyer, R. (eds): *Die Fauna Südwest-Australiens*: **3**(5): 137–144 G. Fischer, Jena.

Wilkinson, C.R. 1980: Nutrient translocation from green algal symbionts to the freshwater sponge *Ephydatia fluviatilis. Hydrobiologia* **75**: 241–250.

Williams, W.D. 1980: *Australian Freshwater Life: The Invertebrates of Australian Inland Waters.* Macmillan, South Melbourne, Victoria: 321 pp.

(accepted 7 October 2008)

ANTARCTIC VIGNETTES I: MAWSON'S SAILMAKER – JAMES FORBES

by Herbert J. G. Dartnall

(with one plate)

Dartnall, H.J.G. 2008 (28:xi): Antarctic vignettes I: Mawson's sailmaker – James Forbes. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 45–46. ISSN 0080–4703. Department of Biological Sciences, Macquarie University, New South Wales 2109, Australia. Email: herbdartnall@pip.com.au

A photograph by Frank Hurley of the sailmaker on the Australasian Antarctic Expedition 1911–14 is identified as the Dundee whalerman James Forbes.

Key Words: James Forbes, sailmaker, Antarctica, Mawson, *Aurora*.

INTRODUCTION AND DISCUSSION

Whereas the wintering personnel and ships' officers of the heroic age of Antarctic exploration are generally well-known, many of the ships' crews are not. Indeed in some instances a complete crew list has never been published. This paper is the first in a series headed "Antarctic Vignettes" seeking to rectify this and record the achievements of some of these little-known men.

Photograph H99, part of the Mawson Collection at the South Australian Museum, is a Frank Hurley portrait of a middle-aged man of indeterminate age with a weather-beaten face, prominent nose and large ears, shown peering off to the left, leaning with his right forearm resting against a wooden box, revealing a gnarled hand with powerful fingers (pl. 1). The picture is entitled "Sails" indicating that he was a sailmaker during the Australasian Antarctic Expedition (AAE) 1911–14; but who was this man?

A complete crew list for all of the voyages of the AAE has never been published, the usual practice being to name only the ships' officers and wintering scientists/expeditioners. Sir Douglas Mawson (Mawson 1930) and Captain John King Davis (Crossley 1997) indicated that the crew of the barquentine-rigged Dundee whaler the SY *Aurora* numbered around 24. However, the total number of men who served on the *Aurora*'s three Antarctic and two sub-Antarctic voyages (1911–14) is closer to 55, with only four of the officers (Captain John King Davis, Second Mate Percy Grey, Third Mate Clarence P. de la Motte and the Chief Engineer F. J. Gillies) and one of the seamen (Oswald McNeice) serving throughout. So it is possible that as many as five men might have served in the capacity of sailmaker during the AAE.

The Captain's pay book (24 AAE), however, only lists one sailmaker – James Forbes. He sailed out from England and served on the first two Antarctic voyages and the two intervening sub-Antarctic ones. Apparently a sailmaker was not deemed necessary for the third and final Antarctic voyage and a donkeyman (A. Beverley) was engaged instead.

James Forbes served on *Aurora* from 26 July 1911 until 18 March 1913 on wages of seven pounds per month and at the end of the expedition was highly commended by Davis. Here the story might have ended but a man of that name (Jimmy Forbes) is mentioned in Hardy (1967) when discussing the 1925–27 voyage to the Southern Ocean in Captain Scott's old research ship the RRS *Discovery* (Hardy 1967, Savours 1992). Could it be the same man?

PLATE 1
Mawson's sailmaker – James Forbes
(photograph: Frank Hurley).

Jimmy Forbes is mentioned on pages 58 and 117 (Hardy 1967). The entry on page 117 recalls his participation in the crossing the line ceremony, which does not help this study, but that on page 58 is of particular relevance.

> *No one, who has not experienced it, can appreciate the full attraction of seeing — and hearing — square-rig sails set. Gradually, one after another, they are unfurled and the yards raised; they are raised to the chorus of some old sea-shanty — "Blow the Man Down," "Whiskey Johnnie" or "Roll the Cotton Home" — as all hands heave on the long rope stretching away aft. We all give a hand at it, or, in the case of the lighter fore-top-gallant sail, we run aft with the rope. A number of our crew have been specially selected for their experience in square-rig; and old "Sails" himself (Sailmaker Jimmy Forbes) in his younger days, had made a number of voyages in the old Dundee whalers. To anyone who has only heard sea-shanties sung in drawing-rooms, or from the concert platform, it is indeed impressive to hear them used functionally: to lighten the labour of heaving and to keep all hands pulling together.*

The final evidence is Dr E. H. Marshall's photograph reproduced opposite page 32 (Hardy 1967). Taken at Christmas 1926 it shows the personnel of the *Discovery*, the *William Scoresby* and the Marine Biological Station at South Georgia, on board the *Discovery* at Grytviken, South Georgia.

Jimmy Forbes is standing two rows behind and a little to the right of Alister Hardy. This man's face has the same facial features as illustrated in Frank Hurley's photograph (pl. 1). (Note that while he is not named in the photo caption in Hardy's book, which only identifies the officers, the same photo appears in Coleman-Cooke (1963) where many more men including Forbes are identified).

According to the RRS *Discovery's* terms of engagement (BT100/305) Jimmy Forbes, who was aged 54, 5 feet 4 inches tall with blue eyes, dark hair and a fresh complexion, joined the *Discovery* on 1 July 1925 as sailmaker on wages of 10 shillings per day and was discharged at the end of the voyage on 3 October 1927. He was then living at 153 Overgate, Dundee. By 1925, square-rigged ships like the *Discovery* were becoming uncommon and a number of old sailors had to be brought out of retirement to man them. Jimmy Forbes was one such man who had last been at sea five years earlier in 1919 on the *Hanover*.

From the above report, it is clear that Jimmy Forbes spent most of his life with the Dundee Whaling Fleet. Could he have gone south to the Antarctic before his 1911–13 AAE engagement, perhaps with the Scottish pioneering expedition of 1892–93, when four ships out of Dundee visited the Antarctic Peninsula in search of whales?

The terms of agreement (BT100/270) for the *Polar Star* (Captain James Davidson) lists a 21-year-old Dundee man by the name of James Forbes as signing the agreement on 5 September 1892. It is clear that the signatures on both the *Polar Star*'s and *Discovery*'s ships' papers are made in the same spidery hand.

James Forbes joined the *Polar Star* on wages of three pounds five shillings per month plus a cut of the profits — five shillings for fast boat and striking money, two shillings and nine pence for every Imperial Tun of oil (whale or seal) harvested, less 2½% for waste; 30 shillings a ton for bone money and five shillings for every 1000 seal skins with cut and damaged skins at half rates. The voyage was not a particularly successful one from a whale/seal-catching point of view and Jimmy Forbes signed-off back in Dundee on 16 June 1893.

James (Jimmy) Forbes was one of the little known men of the early days of Antarctic exploration. He was born in Dundee in about 1871 and served in the specialist role of sailmaker on three Antarctic expeditions spanning 35 years. He first went south as a 21-year-old on the *Polar Star* with the Dundee whaling expedition of 1892–93. He next served on the *Aurora* with Sir Douglas Mawson's Australasian Antarctic Expedition (1911–14) and finally he took part in the *Discovery* Investigations (1925–27). While nothing further is known about this Dundee whalerman he deserves to be more widely recognised.

ACKNOWLEDGEMENTS

I thank Mark Pharaoh and the South Australian Museum for permission to reproduce Frank Hurley's photograph of Mawson's sailmaker.

REFERENCES

24AAE: Captain's pay book part of the Mawson Collection held at the South Australian Museum.

BT 100/270: Board of Trade file held at the National Archives Kew, London.

BT 100/305: Board of Trade file held at the National Archives Kew, London.

Coleman-Cook, J. 1963: *Discovery II in the Antarctic.* Odhams Press Ltd, London: 255 pp.

Crossley, L. 1997: *Trial by Ice: The Antarctic Journals of John King Davis.* Bluntisham Books, Huntingdon and Erskine Press, Norwich: 203 pp.

Hardy, Sir A. 1967: *Great Waters.* Collins, London: 542 pp.

Mawson, D. 1930: *The Home of the Blizzard.* Abridged popular version. Hodder and Stoughton Ltd, London: 438 pp.

Savours, A. 1992: *The Voyages of the Discovery.* Virgin Books, London: 384 pp.

(accepted 5 August 2008)

ANTARCTIC VIGNETTES II: THE SEARCH FOR S. TASMAN, AB, ON THE *TERRA NOVA*, 1903–04

by Herbert J. G. Dartnall

(with two plates)

Dartnall, H.J.G. 2008(28:xi): Antarctic vignettes II: The search for S. Tasman, AB, on the *Terra Nova*, 1903–04. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 47–48. ISSN 0080–4703. Department of Biological Sciences, Macquarie University, New South Wales 2109, Australia. E-mail: herbdartnall@pip.com.au

The Tasmanian seaman, Tasman Spaulding, served on the steam-powered wooden barque SY *Terra Nova* on her 1903–04 voyage to Antarctica. Throughout his life he was beset by official incompetence. The records of his birth, death and marriage all contain mistakes, and a clerical error in 1904 that reversed his first and last names meant he could not be traced. Consequently he never received the bronze Polar Medal awarded for his service as an Able Seaman on the *Terra Nova* in 1903–04. The medal entitlement of three other crew members — Robert Christie, Alexander McNeill and John M. D. Strachan — is challenged.

Key Words: S. Tasman, Tasman James Spaulding, SY *Terra Nova*, 1903–04, Polar Medal, Antarctic exploration.

THE FOUR MISSING POLAR MEDALLISTS

Little is known about many of the members of the ships' crews from the heroic era of Antarctic exploration. Interesting information has recently come to light concerning the Tasmanian seaman, Tasman Spaulding. Of the 31 men awarded bronze Polar Medals for their service on board the *Terra Nova* in 1903–04 (Poulsom & Myres 2000) four never received their medals. The Admiralty file (ADM 171/61), which lists the medal recipients, is annotated "no address known" for Robert Christie, Alexander McNeill, M. Strachan and S. Tasman.

It is not clear why three of these men — Christie, a 26-year-old from Glasgow, McNeill, a 57-year-old from Argyle, and Strachan, a 30-year-old also from Scotland — were recommended for Polar Medals in the first place. According to the ship's log (Board of Trade file BT 100/50) all three men joined the *Terra Nova* at Lyttelton, New Zealand, in May 1904 for the voyage back home to Sheerness via the Cape. If they did not go south they should be ineligible for the award. Nevertheless all three were recommended (Admiralty file ADM 1/7848). A sort of justice appears to have been served insofar as they were never presented with their medals.

TASMAN SPAULDING

The circumstances of the fourth man are completely different. Tasman Spaulding, a 23-year-old from Dunalley, Tasmania, joined the *Terra Nova* at Hobart on 3 December 1903, and sailed with her on the 1903–04 relief voyage to the Antarctic. He clearly signs his name Tasman Spaulding, in a thin spidery hand in the ship's log (Board of Trade file BT 100/50). The *Terra Nova* under Captain Henry McKay had been engaged by the Royal Navy to accompany the Steam Yacht *Morning* to McMurdo Sound to assist in releasing HMS *Discovery* from the ice and bringing home the members of Captain Scott's National Antarctic Expedition. This was duly accomplished (Scott 1905, Aldridge 1999) and on 18 February 1904 all three ships headed north. When the *Terra Nova* reached Lyttelton, Spaulding signed off (5 May 1904) and presumably made his own way home. In due course he was recommended for the Polar Medal in bronze; however, someone accidentally reversed his first and last names and the award was gazetted in the name of S. Tasman. No one of that name could be found when the medals came to be presented and Tasman Spaulding never knew that his good services on board the *Terra Nova* had been recognised.

PLATE 1
Tasman James Spaulding.

THE SEARCH

In 2004, in the Archives Office of Tasmania, I came across Tasman's marriage entry. I also located his birth date and a

record of probate. A subsequent examination of the original records showed that all three of these records had minor, but misleading, errors. On his birth record the family name is spelt Spalding; on the marriage record his wife's second name is given as Charlotte not Isobel (note that while the marriage certificate gives Charlotte, the family, probate record and gravestone all give Isobel), and on the probate record his year of death is given as1940 when he died one year earlier.

All three records did confirm that Tasman Spaulding lived in Dunalley. Further investigation revealed that members of the Spaulding family still lived locally. Contact was made, and through them, with an old family friend William (Bill) Dunbabin, who had known Tas when he (Bill) was a boy. Bill, together with two of Tas's nephews, Jim Spaulding and George Whitehouse, provided the information on which the obituary given below is based.

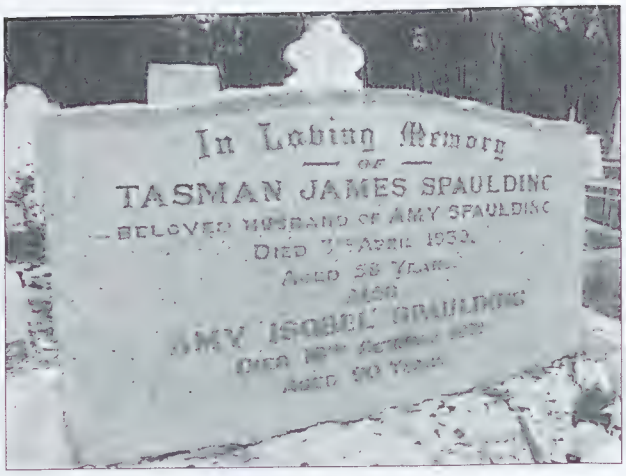


PLATE 2
Tasman Spaulding's headstone in the Dunalley Cemetery.

OBITUARY: TASMAN JAMES SPAULDING

Tasman James Spaulding was born on 24 September 1880, the son of Henry James and Ann Spaulding (née Longmore) of Dunalley, Tasmania. The birth was registered in Sorell, notified by a Trooper (Police Constable) from Bream Creek. Tasman went to the local school and spent much of his early life as a sailor and fisherman. One day in 1900, while on the Hobart waterfront, he and Claude Button, a friend, saw that the square-rigger the *Ethel* was advertising for Able Seamen. Both men signed-on after checking with their respective families, and sailed for England. They were in the English Channel when they learnt of the death of Queen Victoria (22 January 1901). Claude returned to Tasmania after a brief sojourn in London, and married Tasman's sister, Elsie Olive Spaulding. Tasman stayed with the square-riggers, rounding Cape Horn three times and plied the Chilean coast in the lucrative nitrate trade. He was a small, stockily-built man about five feet six inches tall (1.68 m), with a broken nose, very strong hands with nimble fingers and a fondness for liquor. Back in Hobart, in late 1903 he joined the *Terra Nova* (pl. 1). He kept a diary while in the Antarctic but unfortunately this has since been lost. However, one story he often related was that he manned one of the oars when the First Mate (Arthur Perry Jackson) set out to harpoon a whale. They got stuck into a large Blue Whale, which took off. Tas said "he'd never gone so fast, in all his life, in a boat and was most relieved when the line was cut as the whale dived under the ice". He was never keen on whaling after that. At the end of the voyage he signed off in Lyttelton and did indeed make his own way back to Australia.

On 5 November 1913 Tasman married his childhood sweetheart Amy Isobel Murphy and moved into the house they had built on a family block of land in Dunalley. They had seven children, six of whom died within a few hours of birth; the seventh, a boy, lingered for some months. Tas had a variety of jobs in those days including working as a rigger in the cement works on Maria Island, but most of the time he worked on the land and went fishing. When his brother-in-law John Clark Murphy died in 1925, Tas gave up fishing to run a 5000-acre (circa 2000-hectare) sheep farm on the Forestier Peninsula for his 12-year-old nephew, Francis Cooper Murphy. Tasman Spaulding, who suffered from bronchitis and asthma most of his life, died at his home of a cardiac syncope on 3 April 1939, aged 58. He is buried in the Dunalley Cemetery, alongside his parents and six of his nine siblings (pl. 2). He shares his grave with three of his children. The others are buried in two tiny graves nearby, none of which is marked. His widow Amy outlived him by 32 years and died in 1971 aged 90.

In 2007 the Spaulding family presented the Australian Antarctic Division with the large portrait photo of Tasman Spaulding (shown in pl. 1) and the ditty box he had while he was on the *Terra Nova*. Both items are on display in the Australian Antarctic Division library.

ACKNOWLEDGEMENTS

I thank the late W. (Bill) Dunbabin of Dunalley who as a young boy lived next door to Tasman Spaulding, and Tas's nephews George Whitehouse and Jim Spaulding for much of the information on which this obituary is based.

REFERENCES

ADM 1/7848: Admiralty file held at the National Archives Kew, London

ADM 171/61: Admiralty file held at the National Archives Kew, London.

Aldridge, D. 1999: *The Rescue of Captain Scott.* Tuckwell Press, Scotland: 215 pp.

BT 100/50: Board of Trade file held at the National Archives Kew, London.

Poulsom, N.W. & Myres, J.A.L. 2000: *British Polar Exploration and Research 1818–1999.* Savannah Publications, London: 729pp.

Scott, R.F. 1905: *The Voyage of the 'Discovery'.* Vols 1 & 2. Smith Elder & Co, London.

(accepted 5 August 2008)

A CONTRIBUTION TO AN INVENTORY OF LICHENS FROM SOUTH SISTER, NORTHEASTERN TASMANIA

by G. Kantvilas, J. A. Elix and S. J. Jarman

(with five plates and one appendix)

Kantvilas, G., Elix, J.A. & Jarman, S.J. 2008 (28:xi): A contribution to an inventory of lichens from South Sister, northeastern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 49–60. ISSN 0080-4703. Tasmanian Herbarium, Private Bag 4, Hobart, Tasmania 7001, Australia (GK*, SJJ); Department of Chemistry, Australian National University, Canberra, ACT 0200, Australia (JAE). *Author for correspondence.

A lichen survey at South Sister, northeastern Tasmania, has yielded 234 taxa. The following 16 are recorded from Tasmania for the first time: *Acarospora veronensis* A. Massal., *Arthothelium macounii* (G. Merr.) W.J. Noble, *Austrolecia antarctica* Hertel, *Bacidia wellingtonii* (Stirt.) D.J. Galloway, *Buellia griseovirens* (Turner & Borrer ex Sm.) Almb., *Coccocarpia pellita* (Ach.) Müll. Arg., *Hafellia subcrassata* Pusswald, *H. xanthonica* Elix, *Hypocenomyce scalaris* (Ach.) M. Choisy, *Illosporium carneum* Fr., *Lecidella pruinosula* (Müll. Arg.) Kantvilas & Elix comb. nov., *Lecidella sublapicida* (Knight) Hertel, *Lepraria eburnea* J.R. Laundon, *Micarea denigrata* (Fr.) Hedl., *Mycoblastus campbellianus* (Nyl.) Zahlbr. and *Mycoporum antecellens* (Nyl.) R.C. Harris. The survey represents the first of its kind for any dolerite peak in Tasmania, and serves as a benchmark for future studies. Aspects of the distribution and ecology of the flora, the occurrence of rare, threatened or otherwise unusual species, and significant range extensions are discussed. The effect of metal-rich run-off from galvanised structures is identified as a potential threat to the flora values of the site.

Key Words: biodiversity, dolerite, flora, *Lecidella*, lichenised fungi.

INTRODUCTION

South Sister (41°32'S 148°10'E) is a small dolerite pinnacle about 800 m a.s.l. in northeast Tasmania, overlooking the settlement of St Marys. Located within State Forest, the peak is a popular vantage point for bushwalkers, rock-climbers and naturalists, as well as being the site for several telecommunications installations. A proposal (in 2005) to harvest timber from a coupe on its southern slopes generated intense interest in the area, as well as considerable opposition from members of the local community. The campaign against logging led to the compilation of extensive data on various aspects of the area, including its natural history. The history of the campaign and much of this information is available at http://www.southsister.org.

As part of the study of the natural history of South Sister, a survey of lichens was conducted, revealing a diverse and interesting flora, rich in seldom-encountered species. In view of the paucity of sound inventory data for lichens for much of Tasmania, we present our results here to serve as a benchmark for future lichen surveys of Tasmania's peaks, and as a permanent record of the many significant species recorded.

METHODS

Fieldwork was conducted by GK and JAE on 10–11 November 2004, and by GK and SJJ on 31 August 2006 and 22 November 2007. The proposed logging coupe was examined although most effort was concentrated on the pinnacle and its immediate environs. Work was conducted within a broad band from the car park at 750 m a.s.l., along the walking track to the pinnacle, on the scree slopes of the pinnacle itself, and along the small rock-climbers' tracks on the slopes that lead to numerous rocky tors. A preliminary overview identified the following major lichen habitats: wet scrub, rock scree, large cliffs and tors, eucalypt woodland and relict rainforest (pls 1–2). The subsequent lichen survey was structured around this classification.

Collections were made of all species for identification or confirmation of identification in the laboratory. Identification involved morphological examination, anatomical examination using high-power microscopy, chemical analyses using standard methods (Orange *et al.* 2001) and comparison with reliably identified herbarium reference specimens. Vouchers of all species recorded are housed at the Tasmanian Herbarium (HO), with some additional material at the Centre for Plant Biodiversity Research in Canberra (CANB). For taxa not identified to species rank, a reference specimen number (e.g., GK 300/06) is provided in parentheses in appendix 1.

Species nomenclature follows McCarthy (2008). Nomenclature of ascus types follows Hafellner (1984).

RESULTS

Overview of the vegetation

The upper slopes of South Sister carry open forest dominated by *Eucalyptus delegatensis* R. Baker. The eucalypts become shorter and more widely dispersed towards the pinnacle and the taller understorey shrubs and trees become increasingly prominent, and dominate where the eucalypts are absent. The most common of these species are *Bedfordia salicina* (Labill.) DC., *Tasmannia lanceolata* (Poiret) A.C. Smith, *Notelaea ligustrina* Vent. and *Pittosporum bicolor* Hook. Several smaller shrubs, including *Cyathodes glauca* Labill., *Oxylobium ellipticum* (Labill.) R. Br. and *Olearia stellulata* (Labill.) DC., are also common. Ferns, mainly *Polystichum proliferum* (R. Br.) C. Presl and *Microsorum pustulatum* (Forst.f.) Copel. on the pinnacle itself, occur below the small trees and shrubs, or in sheltered spots among the rocks. Grasses are locally common in open areas. One very small patch of relict rainforest, dominated by a few trees of *Atherosperma*

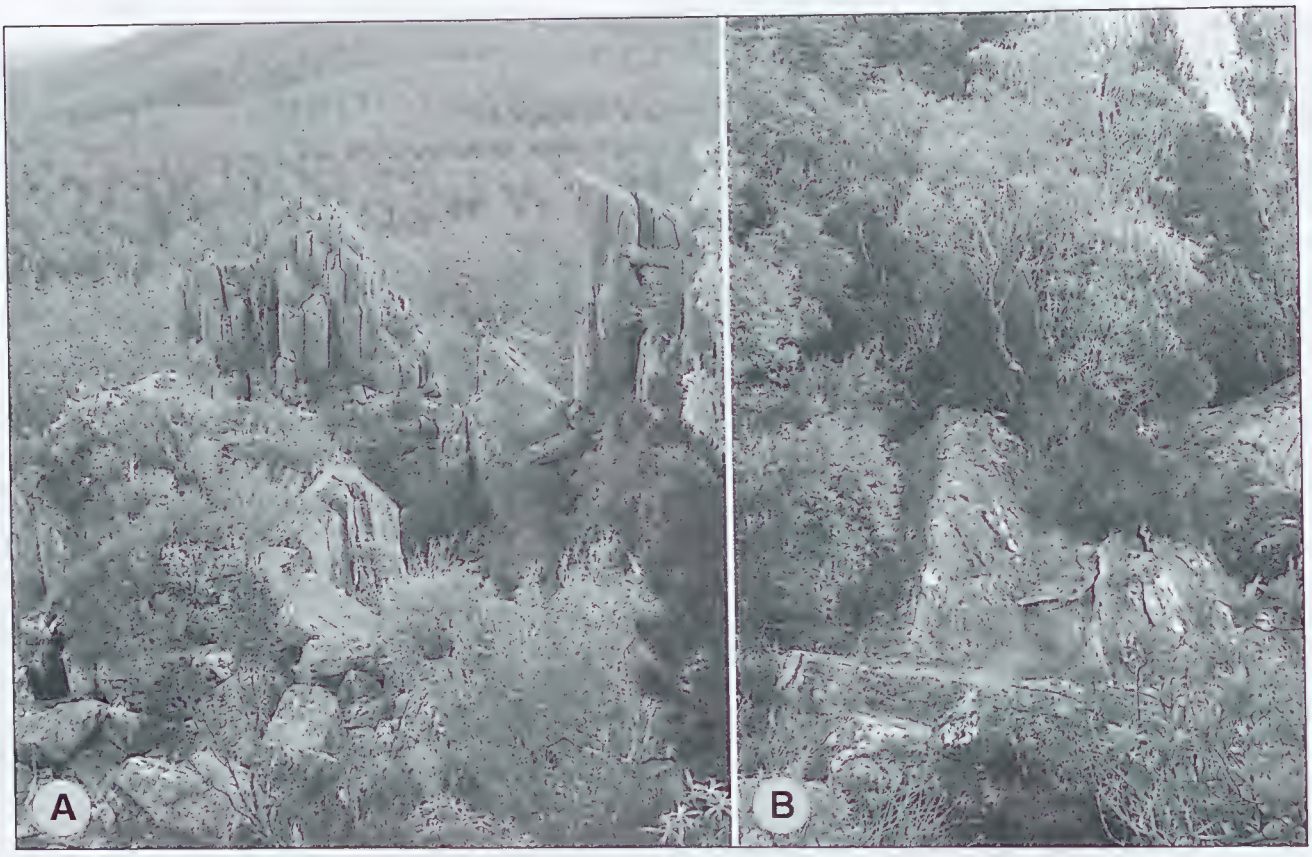


PLATE 1

Vegetation of South Sister. (A) Dolerite tors emergent from wet scrub, with open eucalypt forest on the lower slopes (background). (B) Dense wet scrub on a scree of large dolerite boulders.

PLATE 2

(A) Dolerite boulders, colonised by a highly diverse lichen flora. (B) Detail of lichen mosaics on dolerite; the dominant species shown here belong to the genus Placopsis.

moschatum Labill., occurs in a relatively fire-protected area on the south side of the pinnacle.

Everywhere on and around the pinnacle the land surface is rocky, limiting the extent and density of the woody plant layer and ensuring plenty of light reaches the ground surface. In more sheltered situations, below overhanging rocks or under a sparse vegetation canopy, the surfaces of rocks, soil and living stems carry a rich flora of mosses, liverworts and lichens, creating an image of lush abundance. Even in exposed sites, on the brightly lit, sloping or vertical rock surfaces where conditions are unfavourable for many bryophytes, the diversity and abundance of lichens remain high.

Lichen inventory

In all, 234 lichen taxa were recorded (appendix 1). This figure includes 16 species that are recorded for Tasmania for the first time; diagnoses, notes and lists of reference specimens for these are given below. Two species new to science were discovered during the survey and have been published elsewhere: *Punctelia transtasmanica* Elix & Kantvilas, also known from Flinders Island and New Zealand (Elix & Kantvilas 2005), and *Trapelia lilacea* Kantvilas & Elix, widespread on dolerite in the Tasmanian highlands (Kantvilas & Elix 2007); the latter has since been recorded in New Zealand (D.J. Galloway, pers. comm.). Additional new species are likely to be present amongst the, as yet, not fully identified material, but await future study.

New records

Acarospora veronensis A. Massal., *Ric. Auton. Lich. Crost.*: 29 (1852)

Thallus areolate, reddish brown; areoles plane to convex to somewhat bullate, dispersed or contiguous, 0.5–1 mm wide, rounded to ± rhomboid; apothecia 1–3 per areole, 0.1–0.5 mm wide, rather sunken and crater-like, with a concave, reddish or blackish brown disc; hymenium 60–100 µm thick; ascospores very numerous in the ascus, 3–5 × 1.5–2 µm. Containing no substances detectable by t.l.c. See Purvis & James (1922) for more details.

At South Sister, this species occurred very abundantly on dolerite rock plates where zinc-rich run-off from galvanised sheds and fences has cleared the rock surface of almost all "naturally-occurring" lichens. In this unusual habitat, it is associated with *Candelariella vitellina* and *Lecanora polytropa*. Elsewhere in Tasmania, it has been found in nutrient-enriched sites (from human urine) such as occur around shelter huts in bushwalking areas.

Specimens examined: TASMANIA: South Sister near summit, 41°32'S 148°10'E, 800 m alt., 31.viii.2006, *G. Kantvilas 339/06* (HO); Rodway Range at Tarn Shelf hut, 42°41'S 146°34'E, 1250 m alt., 28.x.2007, *G. Kantvilas 324/07* (HO).

Arthothelium macounii (G. Merr.) W.J. Noble, *Mycotaxon* 28: 91 (1987)

Thallus immersed to absent; fruiting bodies arthonioid, 0.2–0.5 mm wide, roundish, convex, basally constricted; hymenium orange-yellow with numerous reddish brown granules, K+ vivid magenta; ascospores broadly ellipsoid, at first hyaline, soon becoming grey-brown, 29–32 × 11–15 µm, macrocephalic, with a prominent terminal, undivided cell and a muriform "tail" having 3–5 transverse and 0–2 longitudinal septa. See Coppins & James (1979) as *Arthothelium ilicinum* var. *reagens* (= *A. macounii*) for further details.

The Tasmanian specimens are from sheltered underhangs on dolerite in wet scrub. The discovery in Tasmania of this uncommon species, previously known only from western Scotland and British Columbia, represents a remarkable range extension. Superficially the Tasmanian specimens differ from typical material by their saxicolous habitat (elsewhere this species is an epiphyte) and the rather convex, almost subglobose fruiting bodies (normally these are flat and adnate); however, the latter feature may be interpreted as a function of the habitat. Anatomically, the similarity of the Tasmanian specimens to northern hemisphere material is unequivocal. There is another, as yet undescribed *Arthothelium* species in Tasmania that also displays an identical K+ magenta reaction in the fruiting bodies, but this differs by having larger ascospores (38–43 × 18–20 µm) that are ellipsoid and muriform throughout.

Specimens examined: TASMANIA: South Sister, 41°32'S 148°10'E, 750 m alt., 10.xi.2004, *G. Kantvilas 431/04 & J.A. Elix* (HO); Hartz Mountains, iii.1963, *P.W. James* (HO).

Austrolecia antarctica Hertel, *Beih. Nova Hedwigia* 79: 453 (1984)

Thallus crustose, bullate-areolate, white-grey to cream-white; areoles to 3 mm wide, mostly with a minutely roughened surface; apothecia lecideine, black, irregularly to 1.5 mm wide, broadly adnate, sometimes nestled deeply amongst the areoles; epihymenium green, unchanged in K; hypothecium purple-brown, unchanged in K; asci approximating the *Catillaria*-type (*sensu* Hafellner 1984), with a well-developed amyloid tholus lacking discernible internal structures; paraphyses very robust, 3–4 µm wide, simple or occasionally bifurcate or anastomosing, with apices unpigmented and not markedly expanded; ascospores hyaline, ellipsoid to ± oblong, simple to 1-septate, 11–19 × 4–7 µm. Containing atranorin (±), norstictic and connorstictic acids; microscope preparations of the thallus produce red, needle-like crystals with the addition of KOH. See Rambold (1989) for further details.

This saxicolous species is also known from the Antarctic Peninsula, South Shetland Islands and mainland Australia (Rambold 1989, Øvstedal & Lewis-Smith 2001). With its conspicuous thallus of bullate areoles, it is easily detected in the field, although there are some, as yet unidentified, superficially similar species growing in identical habitats in the Tasmanian flora. Anatomically it is best identified by its *Catillaria*-type asci and 0–1-septate ascospores. It grows on exposed boulders and is likely to be more widespread in alpine areas but rarely collected.

Specimens examined: TASMANIA: South Sister, 41°32'S 148°10'E, 780 m alt., 22.xi.2007, *G. Kantvilas 357/07* (HO); The Knuckle, 1400 m alt., 8.iv.1996, *G. Kantvilas 4/96* (HO).

Bacidia wellingtonii (Stirt.) D.J. Galloway, *New Zealand J. Bot.* 21: 192 (1983)

Thallus crustose, effuse, whitish or greenish grey; apothecia basally constricted, superficial, mostly to 0.6 mm wide, with a black, plane disc and pale red-brown margin; epihymenium green, ± unchanged in K, N+ vivid lilac; ascospores very tightly coiled in the ascus, filiform, tapering towards one end, 50–60 × 3–4 µm, up to 15-septate. See Galloway (1985) for full description.

The genus *Bacidia* is well represented in Tasmania but most species remain unidentified pending a detailed study of

the group. *Bacidia wellingtonii* is characterised by the green epithecium and the tightly coiled ascospores. In Tasmania, it occurs on smooth bark in shade in wet forest. It is also known from New Zealand.

Specimens examined: TASMANIA: South Sister, 41°32'S 148°10'E, 750 m alt., 31.viii.2006, *G. Kantvilas 313/06* (HO); Simons Road near Ben Nevis, 830 m alt., 7.xii.1981, *G. Kantvilas 1084/81* (BM, HO).

Buellia griseovirens (Turner & Borrer ex Sm.) Almb., *Bot. Not.* 1952: 247 (1952)

Thallus crustose, greyish white, sorediate; soralia discrete and roundish, to 0.7 mm wide, sometimes becoming confluent, concolorous with the thallus or pale to dark greenish grey; apothecia black, lecideine, to 1 mm wide, with disc mostly plane and margin persistent; hymenium lacking oil droplets; asci 8-spored; ascospores grey-brown to dark brown, ellipsoid, 18–26 × 10–12 µm, submuriform, with 1–3 transverse and 0–1 longitudinal septa. Containing atranorin and norstictic acid; thallus P+ orange, K+ yellow red. See Orange *et al.* (1992) and Nordin (2000) for further descriptions.

This is a cosmopolitan temperate species that is relatively common in Tasmania in open woodlands where it occurs on bark or wood. Understorey trees such as *Banksia marginata* Cav. are a particularly favoured host. When fertile, the brown, submuriform ascospores are diagnostic. Sterile specimens can be determined by their chemical composition. Superficially similar, sorediate species include *Trapeliopsis flexuosa* (which is C+ red) and *Catillochroma pulverea* (which is K–, P+ red).

Specimens examined: TASMANIA: E of Lake Leake, 42°01'S 147°55'E, 400 m alt., 24.iv.1996, *G. Kantvilas s.n.* (HO); South Sister, 41°32'S 148°10'E, 750 m alt., 10.xi.2004, *G. Kantvilas 287/04 & J.A. Elix* (HO); W of New Norfolk along Glenora Road, 42°47'S 147°02'E, 90 m alt., 19.ii.1997, *G. Kantvilas 54/97* (HO); 1 km N of Lake Ironstone, 41°42'S 146°28'E, 1190 m alt., 20.xi.2005, *G. Kantvilas 335/05* (HO); 2 km N of Stonehurst Sugarloaf, 42°31'S 147°48'E, 350 m alt., 17.vi.2003, *G. Kantvilas 348/03* (HO).

Coccocarpia pellita (Ach.) Müll. Arg. *emend.* R. Sant., *Symb. Bot. Upsal.* 12(1): 420 (1952)

Thallus foliose, lead-grey, with lobes flabellate, broadly rounded, 1–5 mm wide; isidia flattened to squamulose, laminal and marginal; underside pale brown, with dense, pale to dark brown rhizines; apothecia lecideine, black, plane to undulate, to 3 mm wide. See Arvidsson (1983) for full description.

This is a widespread tropical to subtropical species. In Tasmania, its most southerly occurrence, it occurs on rocks in sclerophyll forest. The morphology of the isidia readily distinguishes this species from two other, superficially similar members of the genus present in Tasmania; that is, the common *C. palmicola* (with terete isidia) and the rare *C. erythroxyli* (lacking isidia).

Specimens examined: TASMANIA: Mt Cameron, 40°59'S 147°56'E, 350 m alt., 22.iv.1997, *G. Kantvilas 126/97 & J.A. Elix* (HO); Little Beach, 41°38'S 148°19'E, 10 m alt., 19.ii.2001, *G. Kantvilas 312/01* (HO); South Sister, 41°32'S 148°10'E, 800 m alt., 10.xi.2004, *G. Kantvilas 308/04 & J.A. Elix* (HO); St Patricks Head, 41°35'S 148°14'E, 7.vii.1973, *G.C. Bratt 73/660* (HO); *c.* 1 km NE of Coles Bay, 42°07'S 148°17'E, 100–110 m alt., 23.iv.2007, *G. Kantvilas 182/07* (HO).

Hafellia subcrassata Pusswald in Marbach, *Biblioth. Lich.* 74: 284 (2000)

Thallus crustose, greyish white; apothecia black, lecideine, mostly to 1 mm wide, with disc plane to somewhat convex and margin persistent; epithecium brown, unchanged in KOH; hymenium inspersed with oil droplets; asci 8-spored; ascospores brown to grey-brown, ellipsoid, 1-septate, 28–36 × 12–14 µm, with relatively weak apical, subapical and septal thickenings and a ± minutely roughened outer wall. Containing norstictic acid with traces of 4, 5-dichlorolichexanthone; microscope preparations of the thallus often develop red, needle-like crystals with the addition of KOH. See Marbach (2000) for further details.

The genus *Hafellia* is well represented but rather poorly known in Tasmania, and much of the literature (e.g., Marbach 2000, Etayo & Marbach 2003) makes scant reference to Tasmanian collections. The Tasmanian specimen is epiphytic on the bark of *Cyathodes glauca*. It grew together with the related *H. bahiana* (Malme) Sheard, which is far more common and widespread in Tasmania, and has an identical thallus chemistry. That species differs from *H. subcrassata* chiefly by the presence of "sedifolia-grey" pigment (see Meyer & Printzen 2000) in the epithecium; this pigment reacts C+, K+ violet (Sheard 1992, Marbach 2000).

Specimen examined: TASMANIA: South Sister, 41°32'S 148°10'E, 750 m alt., 10.xi.2004, *G. Kantvilas 367/04 & J.A. Elix* (HO).

Hafellia xanthonica Elix, *Australas. Lichenol.* 59: 36 (2006)

Thallus crustose, pale grey to yellowish grey; apothecia black, lecideine, mostly to 1.5 mm wide, with disc plane to somewhat convex and margin persistent; epithecium brown, unchanged in KOH; hymenium inspersed with oil droplets; asci 8-spored, but sometimes with up to six ascopores aborted; ascospores brown to grey-brown, ellipsoid, 1-septate, 14–30(–35) × 6–13(–15) µm, with apical and subapical thickenings. Containing 4, 5-dichlorolichexanthone. See Elix (2006) for further details.

Specimen examined: TASMANIA: southern slope of South Sister, 41°32'S 148°10'E, 640 m alt., 10.xi.2004, *J.A.Elix 28694 & G. Kantvilas* (CANB).

Hypocenomyce scalaris (Ach.) M. Choisy, *Bull. Mens. Soc. Linn. Soc. Bot. Lyon* 22: 103 (1953)

Thallus squamulose; squamules to 1.5 mm wide, pale beige to yellowish, discrete, scattered or imbricate, with margins incised or crenulate, usually somewhat upturned, sorediate; apothecia mostly to *c.* 1 mm wide, brown to black, sometimes slightly bluish pruinose, with plane or undulate disc and persistent, flexuose margin. Containing lecanoric acid; squamules C+ red. See Timdal (1984) for full description.

This species is widespread in temperate areas in both hemispheres, and has been recorded throughout the Australian mainland (McCarthy 2008). Like other members of the genus, it is typically found on eucalypt wood or bark. The presence of soredia distinguishes it from the closely related, very common *H. australis* that occurs in identical habitats.

Specimens examined: TASMANIA: southern slope of South Sister, 41°32'S 148°10'E, 640 m alt., 10.xi.2004, *G. Kantvilas 381/04 & J.A. Elix* (HO); E of Lake Leake, 42°01'S 147°55'E, 400 m alt., 24.iv.1996, *G. Kantvilas s.n.* (HO); W of New Norfolk along Glenora Road, 42°47'S 147°02'E, 90 m alt., 19.ii.1997, *G. Kantvilas 49/97* (HO);

The Hazards near Wineglass Bay Lookout, 42°09'S 148°17'E, 180 m alt., 19.vii.2005, *G. Kantvilas 180/05* (HO); W of Tahune Bridge, 43°06'S 146°41'E, 120 m alt., 2.v.2006, *G. Kantvilas 212/06* (HO).

Illosporium carneum Fr., *Syst. Mycol.* 3: 259 (1822)

This is a licheniciolous fungus growing on the thallus of *Peltigera* species, recognised by its bright orange conidiomata to *c.* 0.5 mm wide. See Hawksworth (1981) for further data.

Specimen examined: TASMANIA: South Sister, 41°32'S 148°10'E, 640 m alt., 10.xi.2004, *G. Kantvilas 390/04 & J.A. Elix* (CANB, GZU, HO).

Lecidella pruinosula (Müll. Arg.) Kantvilas & Elix comb. nov.

Basionym: *Lecidea pruinosula* Müll. Arg., *Flora* 65: 486 (1882). Type: Australia: New South Wales, corticola ad Twofold Bay, *T. White* (holotype: G!).

= *Lecidea cerarufa* (Shirley) Zahlbr., *Cat. Lich. Univ.* 3: 746 (1925); *Biatora cerarufa* Shirley, *Pap. & Proc. Roy. Soc. Tasmania* 1893: 217 (1894). Type: Australia: Tasmania, on bark, Bower Track, Mt Wellington, *W.A. Weymouth 141* (holotype: BRI!).

Thallus crustose, creamish white, thin, smooth or somewhat scurfy, often rather patchy, diffuse; apothecia lecideine, 0.3–1 mm diam., with disc pale pink, orange or reddish brown, usually whitish grey-pruinose, at least when young, typically persistently plane and only rarely becoming convex with age; margin persistent, typically elevated above the level of the disc, with the rim pale orange to brown and the sides usually much paler, in section composed of radiating hyphae inspersed with crystals that fluoresce in polarised light but do not dissolve in KOH; hypothecium (30–)80–110 µm thick, colourless to pale yellowish; hymenium 80–110 µm thick, colourless, with a red-brown epithecial layer composed of granules that do not dissolve in KOH; asci 8-spored, 55–70 × 14–24 µm, of the *Lecanora*-type but with the masse axiale ± barrel-shaped; paraphyses 1.5–2 µm thick, wavy, simple to very sparingly branched, rather coherent in water, not capitate; ascospores hyaline, broadly ellipsoid, ovate to sometimes almost subglobose, (12–)14–18(–20) × (8–)10–14 µm. Chemistry: pannarin (± minor), dechloropannarin (± minor), norpannarin (± trace), 3-*O*-methylthiophanic acid (± major), 2,5,7-trichloro-3-*O*-methylnorlichexanthone (minor or major), 5,7-dichloro-3-*O*-methylnorlichexanthone (± minor), thiophanic acid (± minor), isoarthothelin (± minor), 3-*O*-methylthiophaninic acid (± trace). See also Kantvilas (1988).

This is a common and widespread species in wet eucalypt forest, rainforest and wet scrub where it occurs on trunks and twigs with smooth bark, including the dead canopy twigs of eucalypts. The concentration of chemical substances in this lichen is rather variable. For example, the occurrence of pannarin, which is often a diagnostic substance easily detected by spot tests (it reacts P+ orange), is very patchy, and is often best detected in the whitish pruina of young apothecia. Although relatively infrequently collected, this species is likely to be widespread in eastern Australia.

Selected specimens examined: TASMANIA: South Sister near summit, 41°32'S 148°10'E, 800 m alt., 10.xi.2004, *J.A. Elix 28633 & G. Kantvilas* (CANB, HO); Pelion Plains, 41°50'S 146°03'E, 850 m alt., 13.iii.1992, *G. Kantvilas 169/92* (HO); Anthony Road, 41°49'S 145°38'E, 480 m alt., 30.iv.1993, *G. Kantvilas 221/93* (HO); Yarlington Tier, 42°32'S 147°18'E, 620 m alt., 28.x.1987, *G. Kantvilas 143/87* (HO); West of Tahune Bridge in the Warra SST, 43°06'S 146°41'E, 180 m alt., 23.v.2006, *G. Kantvilas 245/06* (HO); Dee Lagoon, 42°16'S 146°36'E, 690 m alt., 15.xi.1964, *G.C. Bratt 1801 & J.A. Cashin* (HO); Florentine Road, 42°28'S 146°30'E, 240 m alt., 10.xi.2005, *G. Kantvilas 310/05* (HO); Lonnavale, 42°51'S 146°47'E, 70 m alt., 28.vi.1964, *G.C. Bratt 1359b & J.A. Cashin* (HO); Sandspit River, 42°42'S 147°50'E, 180 m alt., 30.x.1988, *A. Moscal 16846* (HO); Kangaroo (Lenah) Valley, 9.xi.1899, *W.A. Weymouth* 952 (HO). Watchorns Hill, Huon Road, 1600 ft alt., 25.i.1899, *W.A. Weymouth 674* (HO).

Lecidella sublapicida (Knight) Hertel, *Mitt. Bot. Staatssamml. München* 199: 444–445 (1983)

Thallus areolate, whitish to cream-white to olive-grey; apothecia scattered, basally constricted, black, mostly to 0.5 mm wide; hymenium colourless, with epihymenium greenish, unchanged in K, N+ red; hypothecium orange-brown, intensifying orange in K and N; ascopsores ellipsoid, 8.5–15 × 5–8 µm. Containing vicanicin and several xanthones; thallus C+ orange. See Rambold (1989) and Knoph (1990) for further descriptions.

Although the genus *Lecidella* remains poorly known in Tasmania, this widespread Australasian species is well-characterised by the presence of vicanicin. It occurs on a variety of rock types, mostly in lowland, open sites in heathland and open eucalypt forest.

Specimens examined: TASMANIA: South Sister, lower slope near car park, 41°32'S 148°10'E, 750 m alt., 10.xi.2004, *G. Kantvilas 419/04 & J.A. Elix* (HO); near Temma, 41°13'S 144°42'E, 21.xi.2001, *G. Kantvilas 1200/01* (HO); Huon Road, 42°54'S 147°17'E, 240 m alt., 30.xii.2000, *G. Kantvilas 570/00* (HO); Couta Rocks, 41°10'S 144°41'E, 9.xii.1993, *G. Kantvilas 304/93 & J.A. Elix* (HO).

Lepraria eburnea J.R. Laundon, *Lichenologist* 24: 331 (1992)

Thallus leprose, whitish, greenish to somewhat yellowish, lacking marginal lobes. Containing alectorialic acid, atranorin (±) and barbatolic acid (±); thallus K-, KC+ fleeting reddish, C-, P+ yellow to orange. See Laundon (1992) for further data.

This is a widespread, pan-temperate species that occurs in shaded underhangs, usually over bryophytes or directly on bark or rock. It is characterised unequivocally by its chemistry.

Specimens examined: TASMANIA: southern slope of South Sister, 41°32'S 148°10'E, 640 m alt., 31.viii.2006, *G. Kantvilas 322/06* & *325/06* (HO); Weindorfers Forest, 41°38'S 145°56'E, 820 m alt., 28.iii.1988, *G. Kantvilas 61/88* (BM, HO).

Micarea denigrata (Fr.) Hedl., *Bih. K. Svenska Vetensk.-Akad. Handl.* III, 18(3): 78, 89 (1892)

Thallus areolate or, more commonly, endoxylic and inapparent; apothecia convex to subglobose, to 0.5 mm wide, immarginate, dark grey to black, C+ red in section; upper part of hymenium with an olivaceous or greyish, C+ violet, K+ violet pigment; ascospores ellipsoid, sometimes curved, (0–)1-septate, 9–16 × 3–4 µm. See Coppins (1983) for full description.

This species is widespread in the temperate northern hemisphere (Coppins 1992a) and occurs on wood, including

milled timber. The genus *Micarea* is very diverse in Tasmania, and contains many undescribed or unrecorded species. Spore morphology and the combination of reactions in C and K distinguish this species from other superficially similar Tasmanian taxa.

Specimens examined: TASMANIA: southern slope of South Sister, 41°32'S 148°10'E, 640 m alt., 10.xi.2004, *G. Kantvilas 389/04 & J.A. Elix* (E, HO); Daley Property, at the "camp ground", 42°21'S 147°48'E, 210 m alt., 24.x.1004, *G. Kantvilas 248/04* (E, HO).

Mycoblastus campbellianus (Nyl.) Zahlbr., *Catal. Lich. Univ.* 4: 3 (1926)

Thallus crustose, whitish, cream or greyish, sorediate; soralia white, 0.2–0.5(–1.2) mm wide, initially discrete, speck-like or sometimes tuberculate, soon becoming diffuse or confluent and spreading unevenly across the thallus; apothecia 0.3–0.5(–0.7) mm diam., scattered, ± superficial, basally constricted, strongly convex and top-shaped when well developed, glossy black to blue-black, rarely dark reddish brown or piebald, immarginate; in section with bright cinereorufa-green pigment (*sensu* Meyer & Printzen 2000), ± unchanged in KOH, N+ crimson, in the excipulum and upper part of hymenium; asci 2(–4)-spored; ascospores ovate to broadly ellipsoid, 27–51(–56) × 17–29(–32) µm, 0(–1)-septate. Containing perlatolic acid, virensic acid, hyperperlatolic acid and protocetraric acid (±); medulla and soralia K-, C-, KC-, P+ orange-red, UV+ white. See Galloway (1985) for full description.

The genus *Mycoblastus* in the southern hemisphere is currently under revision and will be treated in detail elsewhere (Kantvilas, unpubl.). *Mycoblastus campbellianus* is a particularly distinctive species, characterised by the combination of a sorediate thallus containing virensic acid (P+ orange-red), and apothecia with blue-green, "cinereorufa-green" pigment. It is widespread in cool to cold parts of the southern hemisphere, including New Zealand, Tasmania, Campbell Island, Staten Island, Tierra del Fuego and southern Chile, usually as an epiphyte in wet scrub or forest.

Selected specimens examined: TASMANIA: South Sister, 41°32'S 148°10'E, 760 m alt., 22.xi.2007, *G. Kantvilas 369/07* (HO); Little Fisher River, 41°45'S 146°20'E, 880 m alt., *G. Kantvilas 437/84 & P.W. James* (BM, HO); Lake Dobson, 42°41'S 146°35'E, 1030 m alt., 13.viii.1981, *G. Kantvilas 652/81 & P.W. James* (BM, HO); Blue Peaks, 41°43'S 146°23'E, 1290 m alt., 20.xi.2006, *G. Kantvilas 416/06* (HO); Long Tarns, 41°47'S 146°21'E, 1270 m alt., 24.xi.2006, *G. Kantvilas 405/06* (HO).

Mycoporum antecellens (Nyl.) R.C. Harris, *More Florida Lichens*: 67 (1995)

Thallus crustose, thin, often whitish, UV–; perithecia abundant, black, 0.2–0.4 mm wide, unilocular, with wall brown, intensifying yellow-brown in KOH; ostiole central; asci 8-spored; pseudoparaphyses highly branched and anastomosing; ascospores relatively large, 27–40 × 8–14 µm, ellipsoid, 1(–3)-septate, hyaline but turning brownish with age. See Coppins (1992b) (as *Arthopyrenia*) for further data.

This species is widespread on smooth bark in the temperate woodlands of Europe and North America (Coppins 1992b) and has also been recorded from New Guinea (Aptroot *et al.* 1997). In Tasmania, it has been recorded from trees with smooth bark (*Nothofagus cunninghamii, Pittosporum bicolor, Banksia marginata, Atherosperma moschatum* and *Tasmannia lanceolata*) in sclerophyll forest, wet scrub and rainforest. It may well be quite widespread but is small, inconspicuous and therefore easily overlooked.

Specimens examined: TASMANIA: Meetus Falls, 41°57'S 147°53'E, 510 m alt., 16.v.1989, *G. Kantvilas 188/89* (HO); E of Lake Leake, 42°01'S 147°55'E, 400 m alt., 24.iv.1996, *G. Kantvilas s.n.* (HO); Savage River Pipeline at 11.5 mile peg, 41°20'S, 145°16'E, 440 m alt., 9.xii.1993, *G. Kantvilas 287/93 & J.A. Elix* (HO); South Sister, 41°32'S 148°10'E, 800 m alt., 10.xi.2004, *G. Kantvilas 395/04 & J.A. Elix* (HO).

DISCUSSION

Diversity and flora values

The lichen floras of Tasmania's mountains have been sampled and studied in a cursory and opportunistic way, especially in the past 25 years, leading to the discovery and description of many species new to science, and the identification of many new records for Tasmania (for example, see various publications by the authors, cited by McCarthy (2008)). However, very few locations have been subjected to rigorous study and analysis. Exceptions include an account of the alpine flora of southwest Tasmania (Kantvilas 1995), and a survey of Mount Sprent, a Precambrian peak in southwest Tasmania, by Kantvilas & Jarman (1991). No inventory data exist for any dolerite peaks in Tasmania, nor for any area in northeast Tasmania, and thus the results presented here are very much a pioneering benchmark.

With 234 taxa, in comparison to 141 at Mount Sprent (Kantvilas & Jarman 1991) and 981 in the whole of Tasmania (McCarthy 2008), the diversity of lichens at South Sister is undeniably impressive. The significant numbers of new records for Tasmania also suggest the area is "special". However, these findings need to be considered against the backdrop of only limited information from elsewhere, that many of the new records are of highly cryptic taxa not easily detected without very thorough searching, or represent species that were already known to the authors from other sites but not formally recorded in the literature for various reasons. Nevertheless, these considerations should not detract from the fact the site supports several very unusual, uncommon and highly restricted lichens.

Noteworthy components of the lichen flora fall into two broad categories. Firstly, there are species that constitute significant range extensions of otherwise not uncommon species. These include *Sagenidium molle*, which is almost exclusively a species of closed rainforest and occurs mainly on old *Nothofagus* trees; its presence at South Sister, in sheltered rock crevices, is highly unusual. There are also three primarily alpine species present: *Arthroraphis citrinella* var. *citrinella*, *Ochrolechia androgyna* and *Pertusaria flavoexpansa*. Although these lichens are common in alpine areas of Tasmania, their occurrence at South Sister represents a considerable extension of range. Like *S. molle*, these species probably represent relicts from a time when the vegetation and microclimate were considerably moister and cooler.

The second category of noteworthy records comprises genuinely rare species. Three of these, *Coccocarpia erythroxyli*, *C. pellita* and *Xanthoparmelia canobolasensis*, were nominated for inclusion on the register of rare and threatened flora under the *Tasmanian Threatened Species Protection Act 1995*

and, although meeting all the criteria set down under the guidelines, were not listed (see http://www.southsister.org).

Coccocarpia erythroxyli: This species is widespread in tropical areas of the world (Arvidsson 1983) and Tasmania represents its southernmost geographical penetration. It is found mostly in remnant wet scrubby forest dominated by *Notelaea ligustrina*, usually surrounded by dry sclerophyll vegetation, and as such is typically at high risk from fire. At most sites, it is represented by only a few tiny, scattered thalli, sometimes confined to a single host tree. It is locally very abundant at South Sister (pl. 3).

Coccocarpia pellita: This species is widely distributed in tropical and subtropical regions of the world (Arvidsson 1983) and, like the preceding species, its discovery in Tasmania represents the most southerly occurrence of this species in the world. It grows on rocks in sclerophyll forests but is never common, being represented at best by a few isolated thalli.

Lecanactis sp.: This is almost certainly a new species, closely related to the common rainforest epiphyte, *L. abietina* (Ach.) Körber, but differing by its yellowish leprose thallus containing schizopeltic, lecanoric and porphyrilic acids. It grows on rocks in sheltered crevices and underhangs, and has also been collected at Den Hill, southeastern Tasmania. It is clearly a very rare species, not treated in the revision of the genus for Tasmania by Kantvilas (2004).

Pertusaria barbatica: This is a very distinctive, epiphytic, isidiate, crustose lichen, known from only one other locality in Tasmania (in a remnant *Melaleuca ericifolia* swamp in the North-West). It also occurs on the southeastern Australian mainland (Archer 1997).

Pertusaria subdactylina: This bipolar species is known in Australasia only from Tasmania, where it has been recorded previously only twice: from Cape Barren Island and Mt Cameron (Kantvilas & Elix 2008). Both of these records are from granite; the South Sister collection is the first from living bark (of *Cyathodes glauca*).

Punctelia transtasmanica: This very uncommon species was not recorded during a statewide survey of the family (Kantvilas *et al.* 2002) and is known elsewhere only from Flinders Island (where it is locally common) and a single locality in New Zealand.

Xanthoparmelia canobolasensis: This species is very rare on the Australian mainland, being known only from the Orange area of New South Wales. It was the focus of a conservation study there (D. Eldridge, unpubl.) and has been listed under the *NSW Threatened Species Conservation Act 1995*. In Tasmania, it has also been recorded near Falmouth. Specific searches for further populations have not been successful.

Threats

Threats to lichens in a Tasmanian context have been discussed by Brown *et al.* (1994) and Kantvilas (2000), highlighting habitat destruction (through clearing and other changes in land management) and fire as being of greatest importance in the natural environment. For non-vascular plants, fragmentation of continuous tracts of natural vegetation is also an important factor that has been widely recognised and quantified, particularly in Europe (Coppins & Coppins 2002). The broad-scale environment of South Sister, although natural, has been subjected to human activity and fire for a considerable period of time, and so can hardly be considered

PLATE 3
Coccocarpia erythroxyli, *an epiphytic species locally abundant in wet scrub.*

"virgin". However, localised parts of the site, such as the rock scree, tors and pockets of wet scrub, where no useable forest products occur and where fire protection is greatest, are for all intents and purposes "pristine". These are the microhabitats where most of the lichens of greatest scientific or conservation interest are to be found.

One noteworthy but previously undocumented threat in the natural Tasmanian landscape, and one that is dramatically evident at South Sister, is the impact of toxic metals leaching from galvanised structures. This effect was first brought to our attention by Tim Rudman (pers. comm.) who observed it at Devils Gullet (northern Tasmania). The impact on the lichen flora can be dramatic, not least at South Sister. At the smallest scale, such as under pipes and fences, the result can be the total elimination of all lichens (pl. 4). On a larger scale, such as around buildings, there is a wholesale replacement of the natural lichen associations, dominated by species of the Parmeliaceae and crustose lichens such as *Ramboldia petraeoides* and *Lecanora farinacea*, by associations generally connected with pollution and nutrient enrichment. Here the dominant species are *Acarospora veronensis* and *Lecanora polytropa*. Given the patchy occurrence of many of the more interesting and rarer lichen species, the impact of galvanised structures and the resultant metal pollution on the flora values of the site could be critical.

Epilogue: the bushfire of December 2006

The South Sister area was burnt by a severe and extensive bushfire in early December 2006 (see http://www.southsister.org/articles7/fire3.htm for images and details). The study site was revisited in November 2007 to ascertain the impact of the fire on the lichen flora.

In general, fires affect the lichen flora by either causing loss or damage to lichen macrohabitat (e.g., vegetation

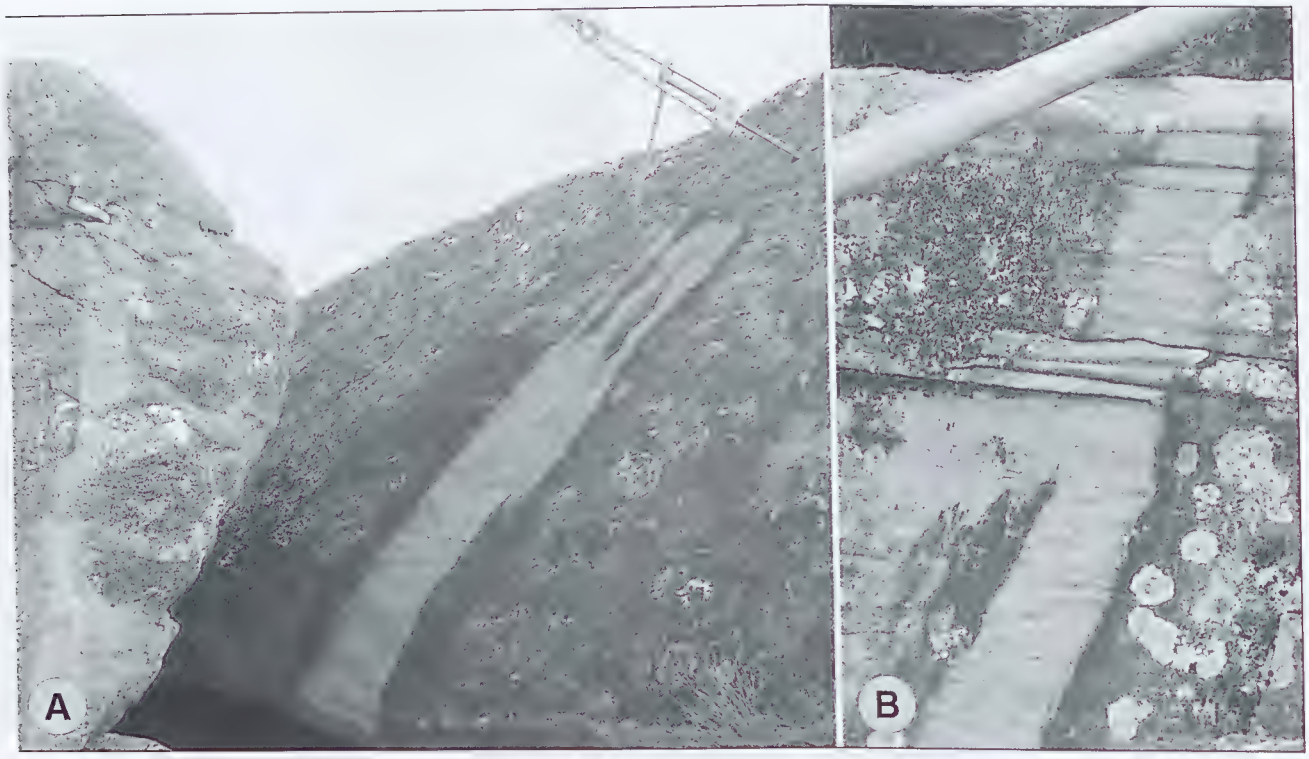


PLATE 4

The impact of galvanised steel on lichens. (A) Band of lichen death in the drip zone and run-off beneath a cable (right) and even beneath a small bolt (left). (B) Detail of the band of lichen death beneath a galvanised pipe.

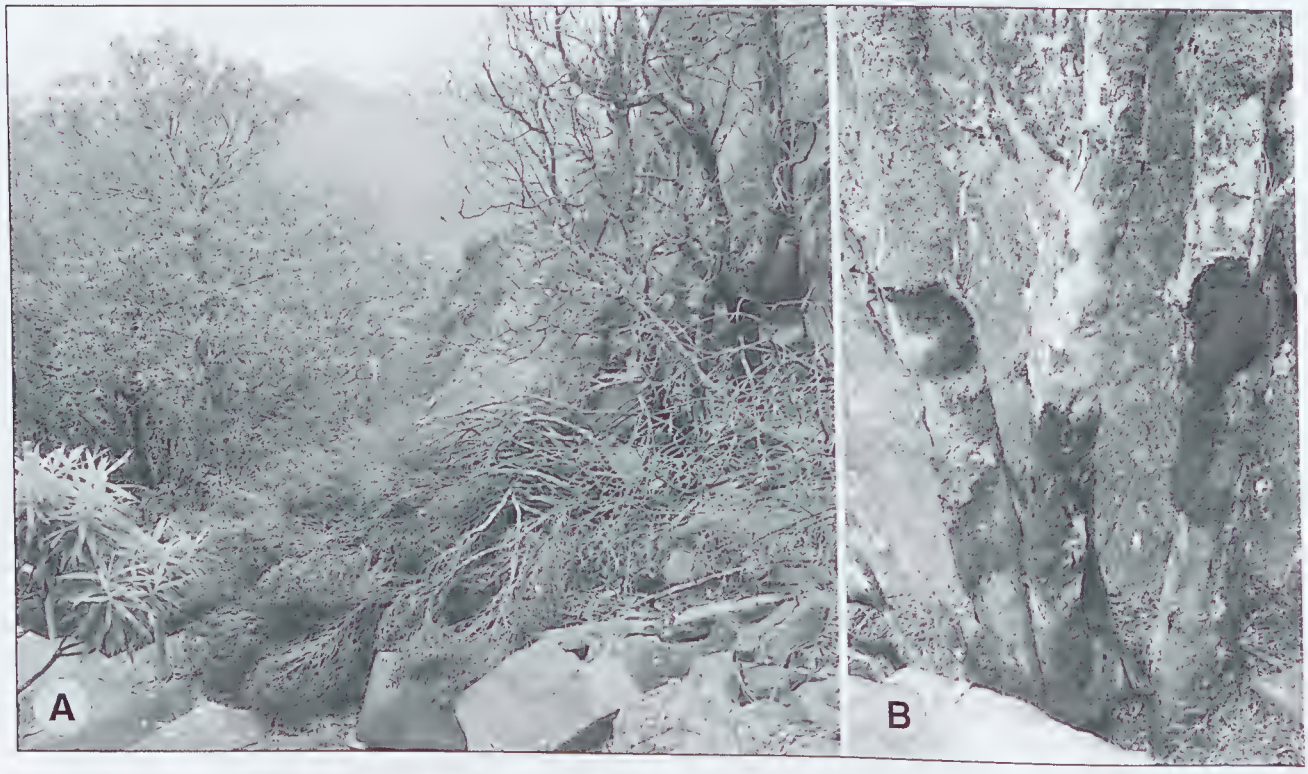


PLATE 5

Effects of the 2006 bushfire. (A) Adjacent patches of burnt (right) and unburnt (left) scrub on rock scree. (B) Mosaic of burnt and unburnt epiphytic lichens and mosses on a single multi-stemmed tree. The intense black patches on the stems are charcoal residues.

communities), by causing loss or damage to lichen substrates (e.g., particular trees and shrubs) or by direct incineration of the lichens themselves. The South Sister fire, at least in the environs of the pinnacle itself, appears to have been relatively patchy. The eucalypt forest on the lower slopes has been extensively burnt, but this vegetation probably supported the least number of lichens. Damage to the rock scree and tors has been minimal, and the flames seemingly "trickled" through the scrub patches, burning some and scorching others, but also leaving areas untouched (pl. 5). The long-term effect on this scrub, which supported a very significant proportion of the lichen flora, is that it will be even more fragmented than before, more prone to drying out, and therefore also more vulnerable to future fires. Some of the impacts on the lichens only become evident over a longer period of time. Our experience elsewhere indicates that following even a patchy fire, attrition of some lichen species continues as they gradually respond to increased exposure to light and dryness, to smoke or heat damage, or to damage to their host. However, given that extensive unburnt lichen habitat remains at South Sister, and that all the main habitat types are still well represented, it is highly likely that the composition of the lichen flora, as recorded before the fire, remains unaltered, and that the special flora values conveyed by the lichens are intact, albeit in a more fragmentary and vulnerable state.

Two of the rarest species, *Coccocarpia pellita* and *Xanthoparmelia canobolasensis*, were not located after the fire. These species had been recorded on the drier, more exposed northern slopes of the peak where the fire was most severe.

ACKNOWLEDGEMENTS

We thank Drs Helmut Mayrhofer and Josef Hafellner (Graz) for identifying *Illosporium carneum*, Dr Brian Coppins for confirming the identity of *Micarea denigrata*, and the curators of the Queensland Herbarium and other herbaria cited for the loan of type and critical specimens. We also thank Julia Weston for her hospitality during our first visit to South Sister, and to other members of the local community through whose encouragement this survey has been brought to publication.

REFERENCES

Aptroot, A., Diederich, P., Sérusiaux, E. & Sipman, H.J.M. 1997: Lichens and lichenicolous fungi from New Guinea. *Bibliotheca Lichenologica* **64**: 1–220.

Archer, A.W. 1997: The lichen genus *Pertusaria* in Australia. *Bibliotheca Lichenologica* **69**: 1–249.

Arvidsson, L. 1983. A monograph of the genus *Coccocarpia*. *Opera Botanica* **67**: 1–96.

Brown, M.J., Kantvilas, G. & Jarman, S.J. 1994: Conservation and reservation of non-vascular plants in Tasmania, with special reference to lichens. *Biodiversity and Conservation* **3**: 263–278.

Coppins, A.M. & Coppins, B.J. 2002: *Indices of Ecological Continuity for Woodland Epiphytic Habitats in the British Isles.* British Lichen Society, London: 36 pp.

Coppins, B.J. 1983: A taxonomic study of the lichen genus *Micarea* in Europe. *Bulletin of the British Museum (Natural History), Botany* **11**: 17–214.

Coppins, B.J. 1992a: *Micarea* Fr. (1825). *In* O.W. Purvis, B.J. Coppins, D.L. Hawksworth, P.W. James & D.M. Moore (eds): *The Lichen Flora of Great Britain and Ireland.* Natural History Museum Publications, London: 371–384.

Coppins, B.J. 1992b: *Arthopyrenia* Massal. (1852). *In* O.W. Purvis, B.J. Coppins, D.L. Hawksworth, P.W. James & D.M. Moore (eds): *The Lichen Flora of Great Britain and Ireland.* Natural History Museum Publications, London: 88–92.

Coppins, B.J. & James, P.W. 1979: New or interesting British lichens III. *Lichenologist* **11**: 27–45.

Elix, J.A. 2006: A new species of *Hafellia* (Physciaceae, lichenized Ascomycota) from Australia. *Australasian Lichenology* **59**: 36–38.

Elix, J.A. & Kantvilas, G. 2005: A new species of *Punctelia* (Parmeliaceae, lichenized Ascomycota) from Tasmania and New Zealand. *Australasian Lichenology* **57**: 12–14.

Etayo, J. & Marbach, B. 2003: *Hafellia alisioae* and *H. gomerana* (lichenized Ascomycetes, Physciaceae), two new species from the Canary Islands, with a key to all known corticolous species. *Lichenologist* **35**: 369–375.

Galloway, D.J. 1985: *Flora of New Zealand Lichens.* P.D. Hasselberg, Government Printer, Wellington: 662 pp.

Hafellner, J. 1984: Studien in Richtung einer natürlicheren Gliederung der Sammelfamilien Lecanoraceae und Lecideaceae. *Beiheft zur Nova Hedwigia* **79**: 241–371.

Hawksworth, D.L. 1981: The lichenicolous Coelomycetes. *Bulletin of the British Museum (Natural History), Botany* **9**: 1–98.

Kantvilas, G. 1988: A re-examination of John Shirley's collection of Tasmanian lichens. *Papers and Proceedings of the Royal Society of Tasmania* **122**(2): 59–67.

Kantvilas, G. 1995: Alpine lichens of Tasmania's south-west wilderness. *Lichenologist* **27**: 433–449.

Kantvilas, G. 2000: Conservation of Tasmanian lichens. *Forest Snow and Landscape Research* **75**: 357–367.

Kantvilas, G. 2004: A contribution to the Roccellaceae in Tasmania: new species and notes on *Lecanactis* and allied genera. *Symbolae Botanicae Upsalienses* **34**(1): 183–203.

Kantvilas, G. & Elix, J.A. 2007: Additions to the lichen family Agyriaceae Corda from Tasmania. *Bibliotheca Lichenologica* **95**: 317–333.

Kantvilas, G. & Elix, J.A. 2008: Additions to the lichen genus *Pertusaria* in Tasmania. *Sauteria* **15**: 249–263.

Kantvilas, G., Elix, J.A. & Jarman, S.J. 2002: *Tasmanian Lichens: Identification, Distribution and Conservation Status. I. Parmeliaceae.* Australian Biological Resources Study, Canberra, and the Tasmanian Herbarium, Hobart: 274 pp.

Kantvilas, G. & Jarman, S.J. 1991: Lichens and bryophytes of the Tasmanian World Heritage Area. I. Mount Sprent. *In* M.R. Banks, S.J. Smith, A.E. Orchard & G. Kantvilas (eds): *Aspects of Tasmanian Botany - A tribute to Winifred Curtis.* Royal Society of Tasmania, Hobart: 149–162.

Knoph, J.G. 1990: Untersuchungen an gesteinsbewohnenden xanthonhaltingen Sippen der Flechtengattung *Lecidella* (Lecanoraceae, Lecanorales) unter Berücksichtigung von aussereuropäischen Proben exklusive Amerika. *Bibliotheca Lichenologica* **36**: 1–183.

Laundon, J.R. 1992: *Lepraria* in the British Isles. *Lichenologist* **24**: 315–350.

McCarthy, P.M. 2008. *Checklist of the Lichens of Australia and its Island Territories.* Australian Biological Resources Study, Canberra. Version 31 January 2008. http://www.anbg.gov.au/abrs/lichenlist/introduction.html.

Marbach, B. 2000. Corticole und lignicole Arten der Flechtengattung *Buellia* sensu lato in den Subtropen und Tropen. *Bibliotheca Lichenologica* **74**: 1–384.

Meyer, B. & Printzen, C. 2000: Proposal for a standardized nomenclature and characterization of insoluble lichen pigments. *Lichenologist* **32**: 571–583.

Nordin, A. 2000: Taxonomy and phylogeny of *Buellia* species with pluriseptate spores (Lecanorales, Ascomycotina). *Symbolae Botanicae Upsalienses* **33 (1)**: 1–117.

Orange, A., Coppins, B.J. & Scheidegger, C. 1992: *Buellia* de Not. (1846). *In* O.W. Purvis, B.J. Coppins, D.L. Hawksworth, P.W. James & D.M. Moore (eds): *The Lichen Flora of Great Britain and Ireland.* Natural History Museum Publications, London: 129–137.

Orange, A., James, P.W. & White, F.J. 2001: *Microchemical Methods for the Identification of Lichens.* British Lichen Society, London: 101 pp.

Øvstedal, D.O. & Lewis-Smith, R.I. 2001: *Lichens of Antarctica and South Georgia. A Guide to their Identification and Ecology.* Cambridge University Press, Cambridge: 411 pp.

Purvis, O.W. & James, P.W. 1992: *Acarospora* Massal. (1852). *In* O.W. Purvis, B.J. Coppins, D.L. Hawksworth, P.W. James & D.M. Moore (eds): *The Lichen Flora of Great Britain and Ireland.* Natural History Museum Publications, London: 59–63.

Rambold, G. 1989: A monograph of the saxicolous lecideoid lichens of Australia (excl. Tasmania). *Bibliotheca Lichenologica* **34**: 1–345.

Sheard, J.W. 1992: The lichenized ascomycete genus *Hafellia* in North America. *Bryologist* **95**: 79–87.

Timdal, E. 1984: The genus *Hypocenomyce* (Lecanorales, Lecideaceae) with special emphasis on the Norwegian and Swedish species. *Nordic Journal of Botany* **4**: 83–108.

(accepted 24 May 2008)

APPENDIX 1

Inventory of lichens from South Sister (numbers in parentheses refer to the unique collection number of a reference specimen in HO).

* indicates a new record
\+ indicates a lichenicolous fungus.

Acarospora sp. (GK 300/06)
**A. veronensis* A. Massal.
Arthonia ilicina Taylor
Arthothelium ampliatum (C. Knight & Mitten) Müll. Arg.
**A. macounii* (G. Merr.) W.J. Noble
Arthroraphis citrinella (Ach.) Poelt var. *citrinella*
**Austrolecia antarctica* Hertel
Bacidia sp. (GK 377/04B)
**B. wellingtonii* (Stirt.) D.J. Galloway
Baeomyces heteromorphus Nyl. ex C. Bab. & Mitten
Belonia uncinata P.M. McCarthy & Kantvilas
Buellia sp. (GK 354/07)
**B. griseovirens* (Turner & Borrer ex Sm.) Almb.
Bullatina microcarpa (Vezda) Brusse
Bunodophoron insigne (Laurer) Wedin
B. patagonicum (C.W. Dodge) Wedin
Calicium adspersum Pers. subsp. *australe* Tibell
C. tricolor F. Wilson
Caloplaca sp. (GK 301/06)
Candelariella vitellina (Hoffm.) Müll. Arg.
Catillaria sp. (GK 314/06)
C. tasmanica Räsänen
Catillochroma pulverea (Borrer) Kalb
Chaenothecopsis savonica (Räsänen) Tibell
Chiodecton colensoi (A. Massal.) Müll. Arg.
C. montanum Thor
Chrysothrix sulphurella (Räsänen) Kantvilas & Elix
Cladia aggregata (Sw.) Nyl.
C. inflata (F. Wilson) D.J. Galloway
C. schizopora (Nyl.) Nyl.
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.
C. confusa R. Sant.
C. corniculata Ahti & Kashiw.
C. gracilis (L.) Willd. subsp. *tenerrima* Ahti
C. cf. *macilenta* Hoffm.
C. merochlorophaea Asahina
C. ochrochlora Flörke
C. pleurota (Flörke) Schaer.
C. pyxidata (L.) Hoffm.
C. ramulosa (With.) J.R. Laundon
C. rigida (Hook.f. & Taylor) Hampe var. *rigida*
C. sarmentosa (Hook.f. & Taylor) C.W. Dodge
C. scabriuscula (Delise) Nyl.
C subsubulata Nyl.
C. sulcata A.W. Archer var. *wilsonii* (A.W. Archer) A.W. Archer
C. verticillata (Hoffm.) Schaer.
Coccocarpia erythroxyli (Spreng.) Swinscow & Krog
**C. pellita* (Ach.) Müll. Arg.
Coccotrema cucurbitula (Mont.) Müll. Arg.
C. porinopsis (Nyl.) Imshaug ex Yoshimura
Coenogonium luteum (Dicks.) Kalb & Lücking
Collema durietzii Degel.
C. fasciculare (L.) Weber ex F.H. Wigg. var. *microcarpum* (Müll. Arg.) Degel.
C. flaccidum (Ach.) Ach.
C. glaucophthalmum Nyl. var. *glaucophthalmum*
C. leucocarpum Hook.f. & Taylor
C. quadriloculare F. Wilson var. *tasmaniae* F. Wilson
C. subconveniens Nyl.
Cresponea plurilocularis (Nyl.) Egea & Torrente
Cystocoleus ebeneus (Dillwyn) Thwaites
Degelia gayana (Mont.) Arv. & D.J. Galloway
Dibaeis arcuata (Stirt.) Kalb & Gierl
Dictyonema sericeum (Sw.) Berk.
Diploschistes scruposus (Schreber) Norman
Flavoparmelia haysomii (C.W. Dodge) Hale

Fuscidea australis Kantvilas var. *australis*
F. australis var. *montana* Kantvilas
F. lightfootii (Sm.) Coppins & James
Hafellia bahiana (Malme) Sheard
**H. subcrassata* Pusswald
**H. xanthonica* Elix
Hertelidea eucalypti Kantvilas & Printzen
H. pseudobotryosa R.C. Harris, Ladd & Printzen
Hypocenomyce australis Timdal
H. foveata Timdal
**H. scalaris* (Ach.) M. Choisy
Hypogymnia lugubris (Pers.) Krog
H. mundata (Nyl.) Oxner ex Rass.
H. pulverata (Nyl.) Elix
H. subphysodes (Kremp.) Filson var. *subphysodes*
H. tasmanica Elix
Hypotrachyna revoluta (Flörke) Hale
H. sinuosa (Sm.) Hale
?*Icmadophila* sp. (GK 261/04)
**+Illosporium carneum* Fr.
Imshaugia aleurites (Ach.) S.F. Meyer
Lecanactis sp. (GK 324/06)
Lecanora farinacea Fée
L. lugubris (C.W. Dodge) D.J. Galloway
L. polytropa (Ehrh.) Rabenh.
Lecidella sp. A (GK 283/04)
Lecidella sp. B (GK 376/07)
**L. pruinosula* (Müll. Arg.) Kantvilas & Elix
**L. sublapicida* (Knight) Hertel
Leifidium tenerum (Laurer) Wedin
Leioderma pycnophorum Nyl.
Lepraria coriensis (Hue) Sipman
**L. eburnea* J.R. Laundon
L. lobificans Nyl.
Leptogium tasmanicum F. Wilson
L. victorianum F. Wilson
Loxospora solenospora (Müll. Arg.) Kantvilas
Maronea constans (Nyl.) Hepp
Megalaria sp. (GK 377/04A)
M. grossa (Pers. ex Nyl.) Hafellner
Megaloblastenia marginiflexa (Hook.f. & Taylor) Sipman
Melanelia subglabra (Räsänen) Esslinger
Menegazzia aeneofusca (Müll. Arg.) R. Sant.
M. confusa P. James
M. myriotrema (Müll. Arg.) P. James
M. nothofagi (Zahlbr.) P. James & D.J. Galloway
M. pertransita (Stirt.) R. Sant.
M. subpertusa P. James & D.J. Galloway
Micarea sp. A (GK 316/06)
Micarea sp. B (GK 361/07)
**M. denigrata* (Fr.) Hedl.
M. intersociella (Stirt.) Coppins
M. micrococca (Körb.) Gams ex Coppins
M. mutabilis Coppins & Kantvilas
Mycoblastus sp. A (GK 356/04)
Mycoblastus sp. B (GK 334/06)
**M. campbellianus* (Nyl.) Zahlbr.
**Mycoporum antecellens* (Nyl.) R.C. Harris
Neophyllis melacarpa (F. Wilson) F. Wilson
Nephroma australe Richard
N. cellulosum (Sm. ex Ach.) Ach.
N. rufum (C. Bab.) P. James
Ochrolechia sp. (GK 332/04)
O. androgyna (Hoffm.) Arn.
Opegrapha sp. (GK 394/04)
Opegrapha viridis Pers. ex Ach.
Pannaria sp. (GK 379/04)
P. elixii P.M. Jørg. & D.J. Galloway
Pannaria farinosa Elvebakk & J. Fritt. Rasm.
P. microphyllizans (Nyl.) P.M. Jørg.
Pannoparmelia wilsonii (Räsänen) D.J. Galloway
Paraporpidia leptocarpa (C. Bab. & Mitt.) Rambold & Hertel
Parmelia cunninghamii Crombie
P. protosignifera Elix & J. Johnst.
P. protosulcata Hale
P. signifera Nyl.
P. tenuirima Hook.f. & Taylor
Parmeliella nigrocincta (Mont.) Müll. Arg.
P. thysanota (Stirt.) Zahlbr.
Parmelina labrosa (Zahlbr.) Elix & J. Johnst.
P. pseudorelicina (Jatta) Kantvilas & Elix
Parmelinopsis afrorevoluta (Krog & Swinscow) Elix & Hale
P. subfatiscens (Kurok.) Elix & Hale
Parmotrema perlatum (Huds.) M. Choisy
P. reticulatum (Taylor) M. Choisy
Peltigera dolichorrhiza (Nyl.) Nyl.
P. polydactyla (Neck.) Hoffm.
Pertusaria barbatica A.W. Archer & Elix
P. flavoexpansa Kantvilas & Elix
P. lophocarpa Körber
P. novaezelandiae Szatala
P. pertractata Stirt.
P. subdactylina Nyl.
Phaeographis mucronata (Stirt.) Zahlbr.
Phlyctis subuncinata Stirt.
Placopsis cribellans (Nyl.) Räsänen
P. parellina (Nyl.) I.M. Lamb
P. perrugosa (Nyl.) Nyl.
Placynthiella icmalea (Ach.) Coppins & P. James
Poeltiaria coromandelica (Zahlbr.) Hertel & Rambold
Polychidium contortum Henssen
Porina constrictospora P.M. McCarthy & Kantvilas
P. decrescens P.M. McCarthy & Kantvilas
Porpidia s. lat. sp. (GK 417/04)
Pseudocyphellaria billardierei (Delise) Räsänen
P. crocata (L.) Vain.
P. gilva (Ach.) Malme
P. glabra (Hook.f. & Taylor) C.W. Dodge
P. multifida (Nyl.) D.J. Galloway & P. James
P. neglecta (Müll. Arg.) H. Magn.
P. rubella (Hook.f. & Taylor) D.J. Galloway & P. James
Psoroma hypnorum (Vahl) S.F. Gray
P. pholidotoides (Nyl.) Trevis.
P. soccatum R. Br. ex Cromb.
Psoromidium aleuroides (Stirt.) D.J. Galloway
Punctelia borreri (Sm.) Krog
P. subrudecta (Nyl.) Krog
P. transtasmanica Elix & Kantvilas
Pyrenula occulta (C. Knight) Müll. Arg.
Racodium rupestre Pers.
Ramboldia blastidiata Kantvilas & Elix
R. brunneocarpa Kantvilas & Elix
R. laeta (Stirton) Kalb, Lumbsch & Elix
R. petraeoides (Nyl.) Kantvilas & Elix
R. plicatula (Müll. Arg.) Kantvilas & Elix
R. stuartii (Hampe) Kantvilas & Elix
Rhizocarpon sp. (GK 416/04)
R. geographicum (L.) DC.

Rinodina subcrustacea (Müll. Arg.) Zahlbr.
R. thiomela (Nyl.) Müll. Arg.
Sagenidium molle Stirt.
Siphula fastigiata (Nyl.) Nyl.
Stereocaulon corticatulum Nyl.
S. ramulosum (Sw.) Räusch.
Sticta limbata (Sm.) Ach.
Tasmidella variabilis Kantvilas, Hafellner & Elix var. *variabilis*
Tephromela atra (Huds.) Hafellner
T. sorediata Kalb & Elix
Thelotrema lepadinum (Ach.) Ach.
Thysanothecium scutellatum (Fr.) D.J. Galloway
Topeliopsis sp. (GK 422/04)
T. muscigena (Stiz.) Kalb
Trapelia coarctata (Sm.) M. Choisy
T. involuta (Taylor) Hertel
T. lilacea Kantvilas & Elix
Trapeliopsis colensoi (C. Bab.) G. Schneid.
T. flexuosa (Fr.) Coppins & P. James
Usnea inermis Motyka
U. oncodes Stirt.
U. rubrotincta Stirt.
U. torulosa (Müll. Arg.) Zahlbr.
Xanthoparmelia amplexula (Stirt.) Elix & J. Johnst.
X. australasica D.J. Galloway
X. canobolasensis Elix
X. congesta (Kurok. & Filson) Elix & Hale
X. dichotoma (Müll. Arg.) Hale
X. digitiformis (Elix & P. Armstr.) Filson
X. epheboides (Zahlbr.) O. Blanco, A. Crespo, Elix, D. Hawksw. & Lumbsch
X. isidiotegeta Elix & Kantvilas
X. loxodella (Esslinger) O. Blanco, A. Crespo, Elix, D. Hawksw. & Lumbsch
X. microcephala Elix & Kantvilas
X. mougeotina (Nyl.) D.J. Galloway
X. neotinctina (Elix) Elix & Johnst.
X. notata (Kurok.) Hale
X. scabrosa (Taylor) Hale
X. segregata Elix & J. Johnst.
X. subprolixa (Nyl. ex Kremp.) O. Blanco, A. Crespo, Elix, D. Hawksw. & Lumbsch
X. tasmanica (Hook.f. & Taylor) Hale
X. tegeta Elix & J. Johnst.

TEMPORAL OCCURRENCE PATTERN OF INSECT PESTS AND FUNGAL PATHOGENS IN YOUNG TASMANIAN PLANTATIONS OF *EUCALYPTUS GLOBULUS* LABILL. AND *E. NITENS* MAIDEN

by D. W. de Little, S. D. Foster and T. L. Hingston

(with four text-figures, four plates and two tables)

de Little, D.W., Foster, S.D. & Hingston, T.L. 2008 (28:xi): Temporal occurrence pattern of insect pests and fungal pathogens in young Tasmanian plantations of *Eucalyptus globulus* Labill. and *E. nitens* Maiden. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 61–70. ISSN 0080-4703. Forest Health Consultant, PO Box 2009, Lower Sandy Bay, Tasmania 7005, Australia (DWdL*); Tasmanian Institute for Agricultural Research, New Town Research Laboratories, 13 St Johns Avenue, New Town, Tasmania 7008, Australia (SDF); 2 Laurel Place, Ulverstone, Tasmania 7315, Australia (TLH). * Author for correspondence. Email: dde64113@bigpond.net.au

The occurrence and distribution with respect to plantation age, of insect pests and fungal pathogens were studied over a five-year period in Tasmanian plantations of the native eucalypt, *Eucalyptus globulus* Labill., and the introduced *E. nitens* Maiden. A total of 45 taxa of pests and pathogens were identified either by their presence, or by their symptoms, from 289 plantation visits distributed in the north and southeast of the island. Thirty-five taxa were identified on each plantation species. The three taxa, Chrysomelinae, *Mycosphaerella* spp., and *Mnesampela privata* were the three most commonly encountered taxa on each host eucalypt species. Other commonly encountered taxa were *Acrocercops laciniella, Gonipterus scutellatus, Phaeothyrolium microthyrioides*, and *Uraba lugens*. Some taxa showed a preference for one or other host eucalypt species while other taxa showed no preference. Some taxa preferred younger plantations, while others were more abundant in older plantations. This plantation age-linked distribution is discussed in relation to foliage phase change in the two host eucalypt species.

Key Words: insect pests, fungal pathogens, eucalypt plantations, Tasmania, *Eucalyptus nitens, Eucalyptus globulus*.

INTRODUCTION

The establishment of eucalypt plantations began in Tasmania in the late 1970s as an alternative source of fibre and solid wood to native forests (Tibbits 1986). After experimentation with several species, the two main species selected for plantation establishment were the native Tasmanian species, *Eucalyptus globulus* Labill., Tasmanian Blue Gum, and the mainland Australian species *Eucalyptus nitens* Maiden, Shining Gum, a native of Victoria and New South Wales. Plantation establishment with these two species has expanded to the point where there are now in excess of 150 000 ha in Tasmania (National Forest Inventory 2005). Harvesting of these plantations commenced in the 1990s and many plantations are now in their second rotation.

Land available for plantation establishment in Tasmania lies between sea level and about 700 m elevation in regions that receive a regular rainfall of greater than 600 mm per annum. *E. globulus* is less cold hardy than *E. nitens* and it is therefore generally established in warmer sites where heavy frost does not occur. As a Tasmanian native tree species it could be expected that *E. globulus* plantations would be attacked by the insect pests and fungal pathogens that attack the species in native regrowth forests. Outbreaks of pests and diseases in Tasmanian eucalypt plantations led to the development of plantation health surveillance programs in the late 1990s (de Little 2002, Stone *et al.* 2003, Carnegie, 2007a, b, 2008).

Both eucalypt species exhibit strong heterophylly with foliage phase change occurring in the early years of the plantation cycle. Observations on pest and disease outbreaks suggested that some might favour juvenile foliage or plantations before canopy closure, while others favoured older plantations post canopy closure and with adult foliage. Predictable temporal variations in pest and disease occurrence could enable more efficient monitoring programs.

The current study reports on insect pests and fungal pathogens encountered in Tasmanian *E. globulus* and *E. nitens* plantations managed by Gunns Limited (formerly North Forest Products) during a five-year plantation health surveillance program between 1998 and 2002.

METHODS

Survey methods

The locations of plantations surveyed on the main island of Tasmania are shown in figure 1.

Plantations were neither thinned nor pruned and typically varied in size from about 10–100 ha with trees planted at a spacing of approximately 3 m^2, giving approximately 1100 trees per ha. Plantation age varied from 1–21 years old. Each plantation visited was surveyed by driving as much as was possible of the perimeter and access roads and also by walking at least three widely spaced transects into the plantation perpendicular to the access road. Length of transect walked was determined by the rate of acquisition of new pest and disease information for the plantation but rarely exceeded 100 m.

Identification methods

Pest and disease organisms were identified by visual detection of their direct presence in association with plantation trees and/or through health disorder symptoms observed on the trees. Where it was not possible to identify causal organisms directly in the field, samples and photographs of the organism and/or its damage symptoms were collected. Samples were maintained in cool storage, and forwarded to relevant experts for identification or compared with descriptions and figures

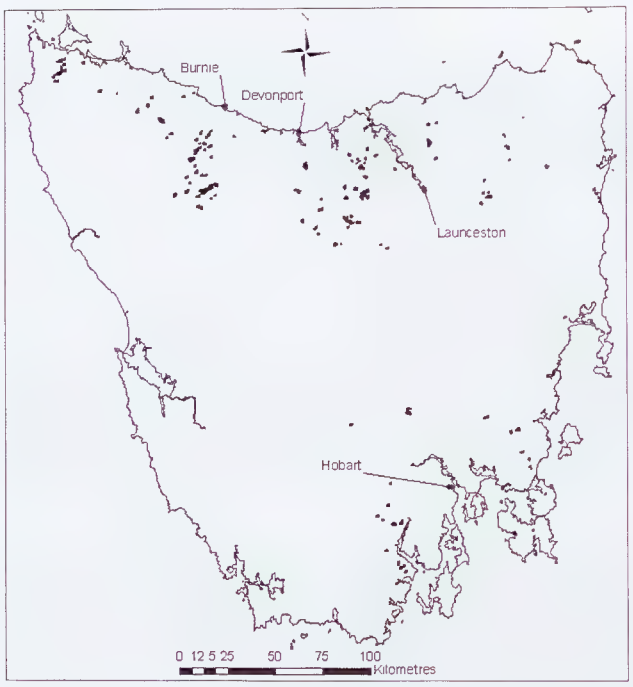


FIG. 1 — Location of plantations within main island of Tasmania.

TABLE 1
Numbers of visits to each age-class of *Eucalyptus globulus* and *E. nitens* plantations

Plantation age-class (yrs)	Total visits	*E. globulus* visits	*E. nitens* visits
1	46	23	23
2	75	30	45
3	47	17	30
4	32	15	17
5	25	5	20
6	19	11	8
7	17	9	8
8	8	3	5
9	6	4	2
10	3	1	2
11	7	1	6
13	1	–	1
15	2	–	2
21	1	1	–
Total	289	120	169

in the relevant literature (Elliott & de Little 1984, Elliott *et al.* 1998, Keane 2000). In most cases causal organisms were identified to species level, but where this was not possible, identification was to genus, sub-family or family level.

Analysis of data

Each pest or pathogen taxon was analysed separately using log-linear models (Venables & Ripley 2002, Agresti 1996) for explaining variation in the number of plantations with damage. Species, year and their interaction were used as possible explanatory variables in the model. Those terms not significant at the 5% level were removed from the model. A goodness-of-fit test is available for these models. This tests the null hypothesis that the model provides an adequate description of the data, a high p-value in this test indicating that there is no evidence to reject this hypothesis.

This type of model is affected adversely by year and species combinations that have extremely low presence (often zero). For this reason these combinations are excluded from the analysis. This completely excludes some pest/pathogen taxa and some taxa by year combinations. When appropriate, these low values can still be plotted with the results from the formal analysis, but they are not taken into account when interpreting the results.

The data set contained several plantations (approximately 12%) that were sampled in more than one year. They were treated as separate plantation sample events for the purpose of analysis.

RESULTS

Description of plantations

A total of 289 plantation visits occurred over the five years that the survey was carried out. The age distribution of these plantations is shown in table 1. Thirty-one plantations were visited in two separate years during the survey period, and three plantations were visited in three separate years during the survey period.

Plantations ranged in altitude between 10 and 730 m above sea level. Annual precipitation varied between approximately 800 and 2000 mm per annum.

Both *E. nitens* and *E. globulus* exhibit heterophylly, undergoing a change in leaf morphology from juvenile to adult foliage as trees age. The rate of transition from juvenile to adult foliage is presented in figure 2. The general pattern appears to be similar for both *E. nitens* and *E. globulus* plantations but not equivalent ($p < 0.001$). It appears that the rate of reduction in purely juvenile plantations is similar for both species but the transition rate from mixed plantations to adult plantations is greater for *E. globulus*.

Pests and pathogens

Twenty-eight taxa (family to species level) of insect pests and 21 fungal pathogens were identified in the plantations surveyed. These were grouped into insect defoliators (13), insect sap-suckers (8), insect borers (4), insect leaf miners (2), insect gall-formers (1), fungal leaf diseases (17), fungal shoot diseases (1), fungal stem cankers (2) and fungal root diseases (1). Full details are given in table 2.

Frequency of occurrence varied greatly between pest and pathogen taxa. Some of the pest and pathogen occurrences were relatively evenly distributed between *E. nitens* and *E. globulus*. Several appeared to favour either one or other host species, e.g., *Ctenarytaina eucalypti* (Maskell, 1890), *Ophelimus* sp. and *Sonderhenia eucalypticola* (A.R. Davis) H.J. Swart & J. Walker on *E. globulus*, and *Armillaria* sp., *Cadmus australis* (Boisduval, 1835) and *Heteronyx* sp. on *E. nitens*.

The criteria described in the Methods section for analysis of pest by species by year combinations, allowed four log-linear model analyses to be carried out for four insect defoliators (Chrysomelinae, *Mnesampela privata* Guenee, 1857, *Uraba*

TABLE 2
Taxa of insect pests and fungal pathogens identified on *Eucalyptus globulus* and *E. nitens* plantations

Taxon	Type	Damage type	Total records	*E. globulus* records	*E. nitens* records
Acrocercops laciniella (Meyrick, 1880)	Insect	Leaf miner	52	23	29
Anoplognathus suturalis Boisduval, 1835	Insect	Defoliator	2	–	2
Armillaria sp.	Fungus	Root disease	15	1	14
Aulographina eucalypti (Cooke & Mass.) Arx & E. Müll.	Fungus	Leaf disease	2	1	1
Botryosphaeria dothidea (Mougeot ex. EM Fries) Cesati & de Notaris	Fungus	Stem canker	1	–	1
Botryosphaeria eucalyptorum Crous, H. Smith & M.J. Wingf.	Fungus	Leaf disease	2	2	–
Botrytis cinerea Pers.	Fungus	Shoot disease	1	1	–
Cadmus australis (Boisduval, 1835)	Insect	Defoliator	12	–	12
Cardiaspina spinifera (Froggatt, 1923)	Insect	Sap sucker	3	1	2
Cardiaspina squamula Taylor, 1962	Insect	Sap sucker	1	–	1
Chrysomelinae (*Paropsis* spp., *Paropsisterna* spp., *Trachymela* spp.)	Insect	Defoliator	110	36	74
Coreidae (*Amorbus obscuricornis* (Westwood, 1842) & *Gelonus tasmanicus* (Le Guillou, 1841))	Insect	Sap sucker	21	1	20
Cryptosporiopsis eucalypti Sankaran & B. Sutton	Fungus	Stem canker	3	–	3
Ctenarytaina eucalypti (Maskell, 1890)	Insect	Sap sucker	15	10	5
Cylindrotrichum sp.	Fungus	Leaf disease	2	1	1
Doratifera pinguis (Walker, 1855)	Insect	Defoliator	1	1	–
Eriococcus confusus Maskell, 1892	Insect	Sap sucker	7	–	7
Eriococcus irregularis Froggatt, 1921	Insect	Sap sucker	1	–	1
Fairmaniella leprosa (Fairm.) Petr. & Syd.	Fungus	Leaf disease	1	–	1
Glycaspis sp.	Insect	Sap sucker	4	3	1
Gonipterus scutellatus Gyllenhal, 1833	Insect	Defoliator	28	26	3
Hesthesis cingulata (Kirby, 1818)	Insect	Borer	3	3	–
Heteronyx spp.	Insect	Defoliator	23	2	21
Hyalinaspis subfasciata (Erichson, 1842)	Insect	Sap sucker	1	–	1
Lamprima aurata Latreille, 1817	Insect	Defoliator	1	–	1
Microsphaeropsis sp.	Fungus	Leaf Disease	1	–	1
Mnesampela privata (Guenée, 1857)	Insect	Defoliator	75	25	50
Mycosphaerella spp.	Fungus	Leaf disease	75	38	37
Myllorhinus dentiferus (Boheman 1858)	Insect	Borer	2	2	–
Ophelimus sp.	Insect	Gall former	14	14	–
Opodiphthera helena (White, 1843)	Insect	Defoliator	1	1	–
Paralaea beggaria (Guenée, 1857)	Insect	Defoliator	2	–	2
Pergidae (*Perga affinis insularis* Riek, 1961 & *Pseudoperga lewisii* (Westwood, 1837))	Insect	Defoliator	3	2	1
Kirramyces eucalypti (Cooke and Massee) J. Walker, B. Sutton & Pascoe	Fungus	Leaf disease	22	3	19
Phaeothyriolum microthyrioides (G. Winter) H.J. Swart	Fungus	Leaf disease	51	9	42
Phoracantha sp.	Insect	Borer	3	1	2
Phylacteophaga sp.	Insect	Leaf miner	1	1	–
Pseudocercospora eucalyptorum Crous, M.J. Wingf. & Marasas	Fungus	Leaf disease	14	4	10
Readeriella mirabilis Syd. & P. Syd.	Fungus	Leaf disease	1	1	–
Rhadinosomus lacordairei Pascoe, 1870	Insect	Borer	2	–	2
Sonderhenia eucalypticola (A.R. Davis) H.J. Swart & J. Walker	Fungus	Leaf disease	13	13	–
Sonderhenia eucalyptorum (Hansf.) H.J. Swart & J. Walker	Fungus	Leaf disease	4	4	–
Thyrinula eucalypti (Cooke & Massee) H.J. Swart*	Fungus	Leaf disease	7	3	4
Tortricidae	Insect	Defoliator	12	10	2
Uraba lugens Walker, 1863	Insect	Defoliator	34	17	17

**Thyrinula eucalypti* is the anamorph of *Aulographina eucalypti.*

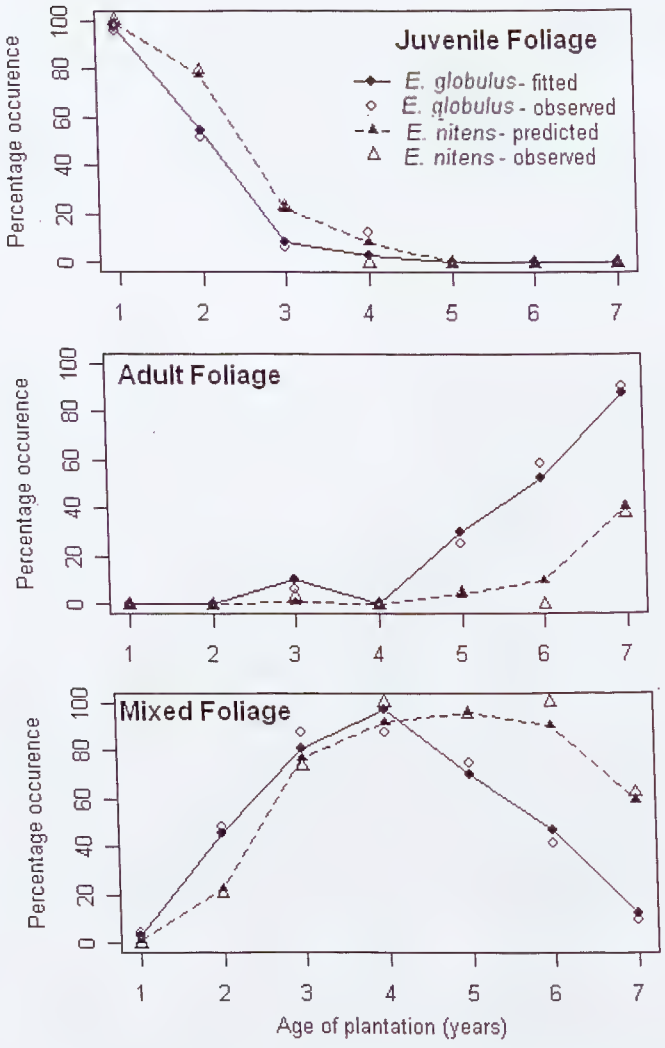


FIG. 2 — Percentage occurrence of plantation foliage types of Eucalyptus globulus *and* E. nitens *at ages from 1–7 years (p=0.610).*

lugens Walker, 1863 and *Gonipterus scutellatus* Gyllenhal, 1833), one insect leaf miner, *Acrocercops laciniella* (Meyrick, 1880), and two fungal leaf diseases (*Mycosphaerella* spp. and *Phaeothyrolium microthyrioides* (G. Winter) H.J. Swart).

Insect defoliators

The most commonly recorded pest taxon was the defoliating Chrysomelinae, a sub-family of leaf beetles (Chrysomelidae) (pl.1A) containing about 36 eucalypt-defoliating species in Tasmania (de Little 1989), of which *Paropsisterna bimaculata* (Olivier, 1807) and *P. agricola* (Chapuis, 1877) are the most common species. Chrysomelinae are generally only present on foliage during the warmer months; however, their presence in plantations was identified by their characteristic scalloping defoliation pattern on leaves that can be recognised at any time of the year (Greaves 1966, de Little 1983). Chrysomelinae were recorded throughout the entire spatial and altitudinal range of plantations. Presence of Chrysomelinae was recorded in both *E. globulus* and *E. nitens* plantations and there was no evidence of preference for one species of eucalypt over another. There was an age effect on the number of plantations with Chrysomelinae damage ($p<0.001$). Young plantations appeared less susceptible than plantations about three years of age and older (fig. 3).

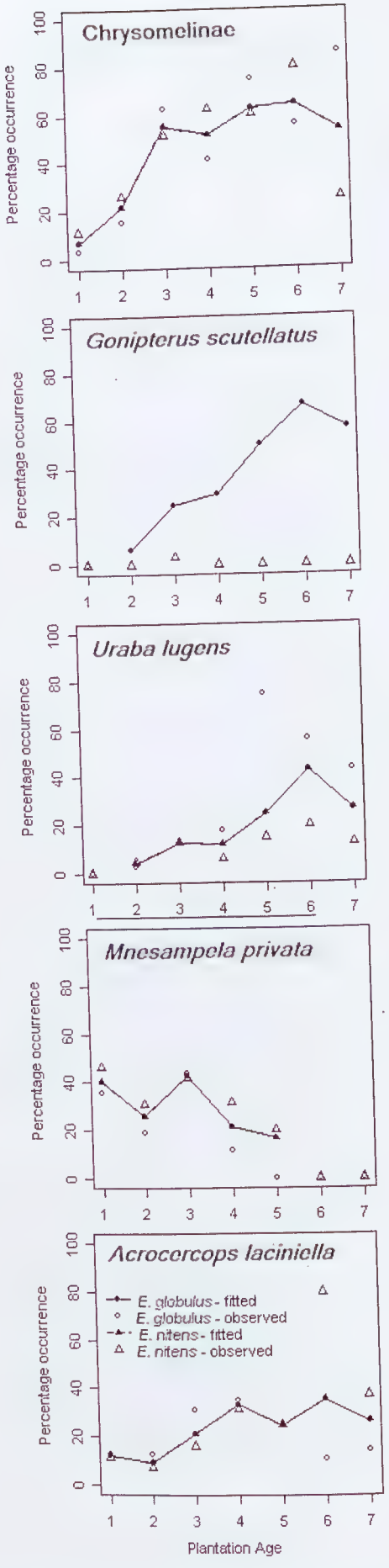


FIG. 3 — Percentage of plantations of Eucalyptus globulus *and* E. nitens *with symptoms of damage caused by Insect Defoliators and Insect Leaf Miners in age classes from 1–7 years (p>0.100).*

The second most commonly recorded insect pest was *Mnesampela privata* (Autumn Gum Moth) (pl. 1B). Presence of this pest was detected by occurrence of eggs or egg cases, larvae, or characteristic webbing and defoliation patterns on leaves (Steinbauer *et al.* 2001). *M. privata* did not prefer one host species over another but the age of the plantation did affect the incidence (p=0.037). The profile of incidence over time indicates that young plantations have higher incidence than older ones (fig. 3). This finding is consistent with the observation that *M. privata* only attacks juvenile foliage (Steinbauer 2002). *M. privata* was recorded throughout the entire spatial and altitudinal range of plantations.

Other commonly recorded insect defoliators were *Uraba lugens* (Gum-leaf Skeletoniser) and *Gonipterus scutellatus* (Eucalypt Snout Weevil) (pl. 1C, D). Presence of both species changed with plantation age (p=0.002 and p=0.02 respectively). It was possible to assess the preference of *U. lugens* to plantation type. This test indicated that there is evidence of preference (p = 0.029). There were insufficient data on *E. nitens* to perform a similar test for *G. scutellatus* (fig. 3).

Less commonly recorded insect defoliators were *Heteronyx* spp (Cockchafers), *Cadmus australis* (Boisduval, 1835) and Tortricidae (Leaf-rollers) (pl. 1E, F, G).

Insect sap-suckers

The most commonly occurring taxon was Coreidae (pl. 2A), identified by the characteristic damage symptoms of wilted or pruned young shoots. This damage is caused by two species, *Amorbus obscuricornis* (Westwood, 1842), Gum-tree Bug, and *Gelonus tasmanicus* (Le Guillou, 1841), Tasmanian Gelonus Bug. Another commonly encountered taxon on very young trees was *Ctenarytaina eucalypti,* Bluegum psyllid (pl. 2B).

Insect borers

None of the four insect borers that were encountered was common or widespread.

Insect leaf miners

Acrocercops laciniella (Blackbutt Leaf-miner) (pl. 2C) was very commonly encountered (mainly in the north of the island) on both eucalypt species. It was recognised by the characteristic "blister" caused by larvae feeding under the leaf epidermis and changed in presence (p=0.028) with increase of plantation age (fig. 3). It appeared to show no preference for either host species.

Insect gall formers

Ophelimus sp. (Blue-gum Chalcid) was encountered only on *E. globulus* in a restricted area in the central north of the island. It was recognised by the characteristic galls formed on young shoots (pl. 2D) that led to twisted and distorted trunks and branches in older trees.

Fungal leaf diseases

The most commonly encountered fungal leaf disease was "Crinkle Leaf" caused by *Mycosphaerella* spp. (pl. 3A). *E. globulus* plantations were more susceptible to attack by *Mycosphaerella* than *E. nitens* plantations (p=0.007). Both types of plantations exhibited a significant (p<0.001) change in incidence over time. Presence appeared to peak in 3–5-year-old plantations, coinciding with maximum quantities of juvenile foliage and the onset of canopy closure and the transition to adult foliage (fig. 4). Carnegie (2007b) observed infection of *E. globulus* subsp. *maidenii* by *Mycosphaerella nubilosa*

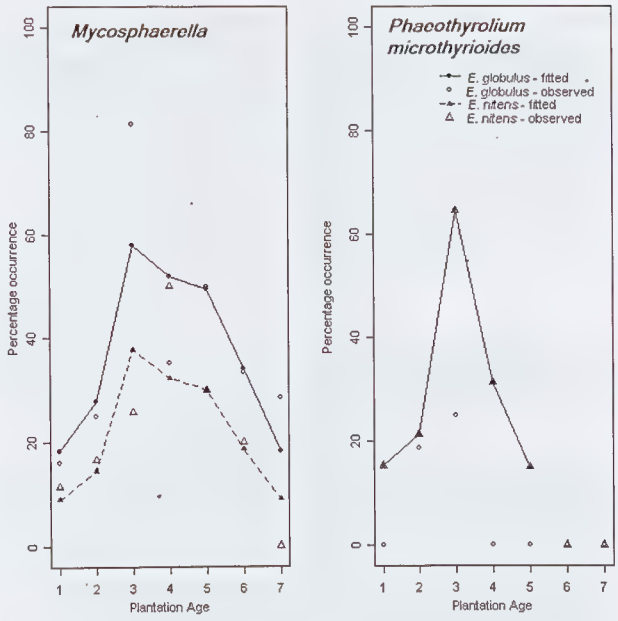


FIG. 4 — Percentage of plantations of Eucalyptus globulus *and* E. nitens *with symptoms of damage caused by leaf diseases in age classes from 1–7 years (p>0.05).*

(Cooke) Hansf. to be highest at age 2–4 years in several trials in New South Wales.

The second most commonly recorded fungal leaf disease was *Phaeothyrolium microthyrioides.* This species was widespread on juvenile foliage and is recognised by the characteristic "oil blotches" on leaves (pl. 3B). It is much more commonly found on *E. nitens* where its presence changed significantly over time (p <0.001). Presence appeared to peak in three-year-old plantations. The presence of *P. microthyrioides* on eucalypt and *Corymbia* plantations in New South Wales was recorded by Carnegie (2007a, b) although not on either *E. globulus* or *E. nitens.*

Other fungal leaf diseases were *Kirramyces eucalypti* (Cooke & Massee) J. Walker, B. Sutton & Pascoe, *Pseudocercospora eucalyptorum* Crous, M. J. Wingf. & Marasas and *Sonderhenia eucalypticola* (A. R. Davis) H. J. Swart & J. Walker (pl. 3C, D, E).

Root diseases

Only one root disease, *Armillaria* sp. (pl. 4), was encountered.

Other fungal pathogens

Neither shoot diseases nor stem canker diseases were common or widespread.

DISCUSSION

Many previous studies of individual insect pest and fungal pathogen taxa on Tasmanian eucalypt plantations have been reported in the literature (Bashford 1993, Yuan 1999). This paper represents the first attempt to quantify temporal distribution of these pests and pathogens together in young *E. globulus* and *E. nitens* plantations.

The two host eucalypt species are regarded as being closely related taxonomically, both being placed in the series *Globulares* Blakely (Brooker 2000), but while *E. globulus* has its main centre of natural distribution in Tasmania,

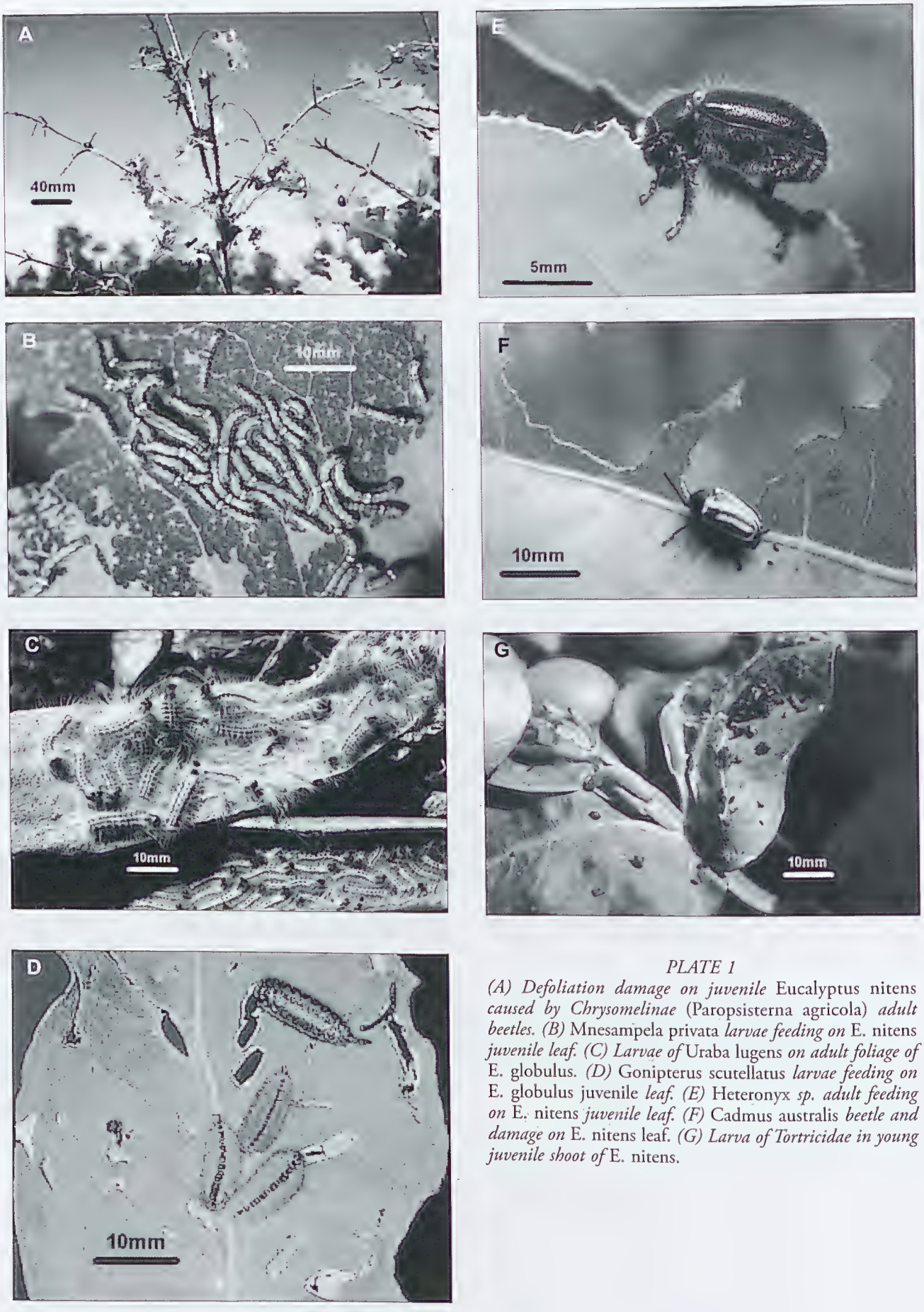


PLATE 1

(A) Defoliation damage on juvenile Eucalyptus nitens *caused by Chrysomelinae* (Paropsisterna agricola) *adult beetles. (B)* Mnesampela privata *larvae feeding on* E. nitens *juvenile leaf. (C) Larvae of* Uraba lugens *on adult foliage of* E. globulus. *(D)* Gonipterus scutellatus *larvae feeding on* E. globulus juvenile *leaf. (E)* Heteronyx *sp. adult feeding on* E. nitens *juvenile leaf. (F)* Cadmus australis *beetle and damage on* E. nitens leaf. *(G) Larva of Tortricidae in young juvenile shoot of* E. nitens.

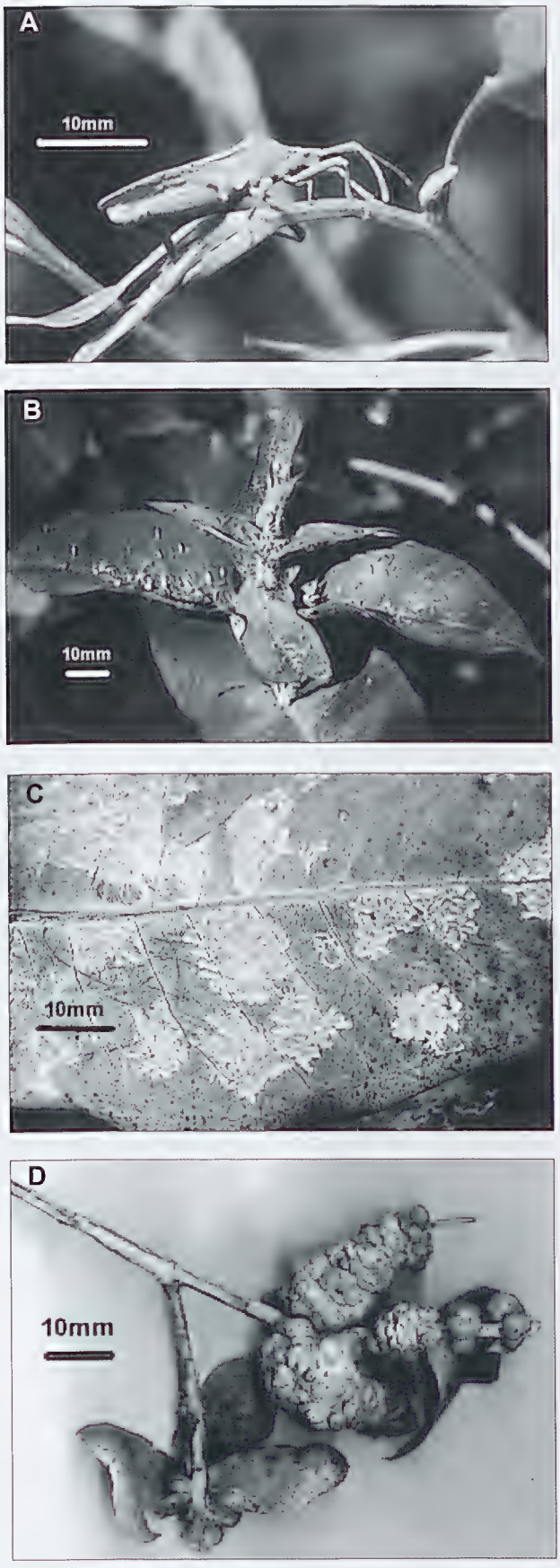


PLATE 2

*(A) Coreid bug (*Amorbus obscuricornis*) on eucalypt shoot (B)* Ctenarytaina eucalypti *on juvenile foliage of* Eucalyptus *globulus. (C)* Acrocercops laciniella *mines on* E. nitens *leaf. (D) Galls on* E. globulus *shoot caused by* Ophelimus *sp.*

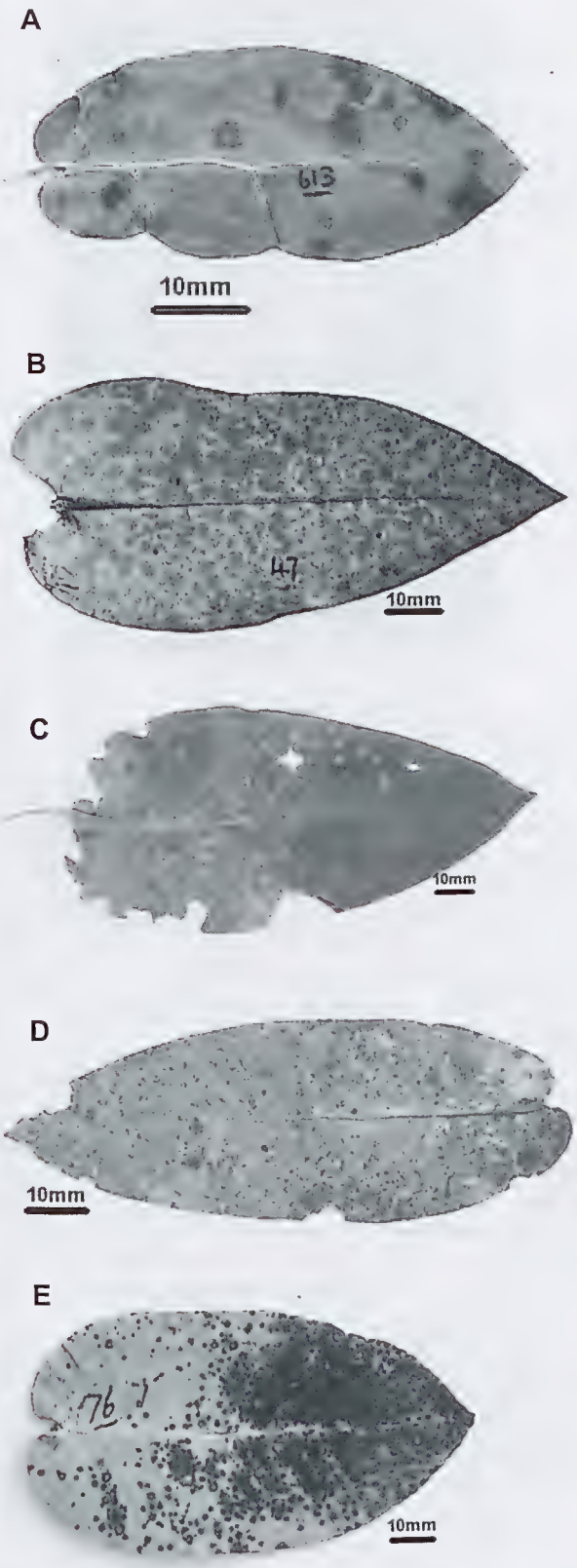


PLATE 3

(A) Mycosphaerella *sp. "Crinkle leaf" lesions on juvenile* Eucalyptus nitens *leaf. (B) Lesions of* Phaeothyrolium microthyrioides *on juvenile* E. nitens *leaf. (C) Lesions of* Kirramyces eucalypti *on juvenile* E. nitens *leaf. (D) Lesions of* Pseudocercospora eucalyptorum *on juvenile* E. nitens. *(E) Lesions of* Sonderhenia eucalypticola *on juvenile foliage of* E. globulus.

PLATE 4
Armillaria *sp. fungal weft at base of dead eucalypt plantation tree.*

E. nitens is an introduced species, occurring naturally in Victoria and New South Wales. At the commencement of this study in 1998, both species had a plantation history of approximately 20 years in Tasmania. Both species exhibit strong heterophylly with the transition to adult foliage exhibiting a similar yet significantly different pattern (fig. 2). The exotic species, *E. nitens*, was shown to be approximately equivalently susceptible to pest and pathogen attack as its native relative, *E. globulus*. (table 2, figs 3, 4).

A total of 45 pest/pathogen taxa were identified in this study with approximately 78% of the taxa occurring on each host. The most commonly encountered pest/pathogen taxa were Chrysomelinae, *Mycosphaerella* spp., *M. privata, A. laciniella, P. microthyrioides, U. lugens* and *G. scutellatus* (table 2). Some of the more common pests/pathogens, while being encountered on both hosts, clearly preferred one host, e.g., *P. microthyrioides, E. nitens, G. scutellatus, E. globulus*.

Attack trends of foliar pests and pathogens with age in plantations up to seven years of age reflected preference for either juvenile or adult foliage. Preference for juvenile foliage was exemplified by *M. privata* (fig. 3). With the fungal leaf pathogens *Mycosphaerella* spp. and *P. microthyrioides*, there was a build up to a peak at age three to four years as plantation canopies closed creating the moister microclimatic conditions that favour some leaf pathogens. Occurrence then declined as the proportion of more resistant adult foliage increased in the plantations (fig. 4). *U. lugens* and *G. scutellatus* are examples of pests that build up slowly as the amount of adult foliage increases (fig. 3).

Information provided in this paper will enable managers of Tasmanian eucalypt plantations to improve timing and efficacy of specific insect pest and fungal pathogen monitoring and management programs. For example, monitoring for Chrysomelinae, *G. scutellatus* and *U. lugens* need only occur in plantations aged three years or greater, whereas monitoring for *M. privata* need only occur in plantations up to five years old. For *Mycosphaerella* spp., monitoring need only occur in plantations aged between two and six years.

ACKNOWLEDGEMENTS

Gunns Limited (formerly North Forest Products) is acknowledged for its support of this work and for the preparation of figure 1. The authors are grateful to Dr Yuan Zi Qing (formerly of Cooperative Research Centre for Sustainable Production Forestry) for his identification of many of the leaf pathogenic fungi, Dr John La Salle (Australian National Insect Collection) for his identification of *Ophelimus* sp., and Mr Dick Bashford (Forestry Tasmania) for his identification of *Cardiaspina* spp. and *Hyalinaspis subfasciata*. Drs Christine Stone, Geoff Allen and Humphrey Elliott kindly commented on the manuscript.

REFERENCES

Agresti, A. 1996: *An Introduction to Categorical Data Analysis.* Wiley Series in probability and statistics. John Wiley & Sons, New York: 312 pp.

Bashford, R. 1993: Insect pest problems of eucalypt plantations in Australia. 4. Tasmania. *Australian Forestry* **56**: 375–377.

Brooker, M.I.H. 2000: A new classification of the genus *Eucalyptus* L'Hér. (Myrtaceae). *Australian Systematic Botany* **13**: 79–148.

Carnegie, A.J. 2007a: Forest health condition in New South Wales, Australia, 1996-2005. I. Fungi recorded from eucalypt plantations during forest health surveys. *Australasian Plant Pathology* **36**: 213–224.

Carnegie, A.J. 2007b: Forest health condition in New South Wales, Australia, 1996-2005. II. Fungal damage recorded in eucalypt plantations during forest health surveys and their management. *Australasian Plant Pathology* **36**: 225–239.

Carnegie, A.J. 2008. A decade of forest health surveillance in Australia: an overview. *Australian Forestry* **71**: 161–163.

de Little, D.W. 1983: Life cycle and aspects of the biology of Tasmanian Eucalyptus Leaf Beetle, *Chrysophtharta bimaculata* (Olivier) (Coleoptera: Chrysomelidae). *Journal of the Australian Entomological Society* **22**: 15–18.

de Little, D.W. 1989: Paropsine chrysomelid attack on plantations of *Eucalyptus nitens* in Tasmania. *New Zealand Journal of Forestry Science* **19**: 223–227.

de Little, D. 2002: Forest health – a proactive approach to pest and disease problems in plantations. *Australian Forest Grower* **25**(3) AFG Special Liftout: 6 pp.

Elliott H.J. & de Little, D.W. 1984: *Insect Pests of Trees and Timber in Tasmania.* Forestry Commission, Hobart: x+90 pp.

Elliott, H.J., Ohmart, C.P. & Wylie, F.R. 1998: *Insect Pests of Australian Forests: Ecology and Management.* Inkata Press, Melbourne: 214 pp.

Greaves, R. 1966: Insect defoliation in the eucalypt regrowth in the Florentine Valley, Tasmania. *Appita* **19**:119–126.

Keane, P.J., Kile, G.A., Podger, F.D. & Brown, B.N. (eds) 2000: *Diseases and Pathogens of Eucalypts.* CSIRO Publishing, Melbourne: 616 pp.

National Forest Inventory 2005: *National Plantation Inventory 2005 Update.* Bureau of Rural Sciences, Canberra: 8 pp.

Steinbauer, M.J. 2002: Oviposition preference and neonate performance of *Mnesampela privata* in relation to heterophylly in *Eucalyptus dunnii* and *E. globulus*. *Agricultural and Forest Entomology* **4**: 245–253.

Steinbauer, M.J., McQuillan, P.B. & Young, C.J. 2001: Life history and behavioural traits of *Mnesampela privata* that

exacerbate population responses to eucalypt plantations: comparisons with Australian and outbreak species of forest geometrid from the northern-hemisphere. *Austral Ecology* **26**: 525–534.

Stone, C., Wardlaw, T., Floyd, R., Carnegie, A., Wylie, R. & de Little, D. 2003: Harmonisation of methodologies for the assessment and reporting of forest health in Australia – A starting point. *Australian Forestry* **66**: 233–246.

Tibbits, W.N. 1986: Eucalypt plantations in Tasmania. *Australian Forestry* **49**: 216–225.

Venables, W.N. & Ripley, B.D. 2002: *Modern Applied Statistics with S. Statistics and Computing*. 4th Edition. Springer, New York: xi+495 pp.

Yuan, Zi Qing 1999: *Fungi Associated with Diseases Detected During Health Surveys of Eucalypt Plantations in Tasmania*: School of Agricultural Science, University of Tasmania: Hobart.

(accepted 26 February 2008)

EUCALYPTUS CORDATA SUBSP. *QUADRANGULOSA* (MYRTACEAE), A NEW TAXON OF RESTRICTED DISTRIBUTION FROM SOUTHERN TASMANIA

by Dean Nicolle, Brad M. Potts and Gay E. McKinnon

(with one text-figure and four plates)

Nicolle, D., Potts, B.M. & McKinnon, G.E. 2008 (28:xi): *Eucalyptus cordata* subsp. *quadrangulosa* (Myrtaceae), a new taxon of restricted distribution from southern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 71–78. ISSN 0080-4703. Currency Creek Arboretum, 15 Rousillion Promenade, Old Reynella, South Australia 5161, Australia (DN*). School of Plant Science and Cooperative Research Centre for Forestry, University of Tasmania, Private Bag 55, Hobart, Tasmania 7001, Australia (BMP, GEMcK). *Author for correspondence. Email: Dean.Nicolle@dn.com.au

Eucalyptus cordata subsp. *quadrangulosa* is described to accommodate western populations of the species, and differs from the typical subspecies most conspicuously in the quadrangular branchlets, and also in the larger and more pointed juvenile leaves, the more flattened peduncles, the larger bi-ribbed flower buds, and the larger fruits. The quadrangular branchlets of the new subspecies are unique in *E.* ser. *Orbiculares.* The new subspecies occurs to the west of, and largely disjunct from, eastern *E. cordata*, and tends to occupy cooler and wetter sites. Some morphologically and geographically intermediate populations are known. Both subspecies of *E. cordata* are of restricted distribution and are known from relatively few, disjunct and generally numerically small populations, and as such are under threat from various natural and human-induced influences. The newly described subsp. *quadrangulosa* is commonly cultivated in cool climates as an ornamental tree for its silvery foliage. A key to *E.* ser. *Orbiculares*, and a distribution map and photographs of representative types of *E. cordata* are presented.

Key Words: *Eucalyptus cordata*, *Eucalyptus cordata* subsp. *quadrangulosa*, silver gum, *Orbiculares*, Tasmania, new subspecies.

INTRODUCTION

Eucalyptus cordata Labill. (Heart-leaved Silver Gum) is a woody shrub or tree restricted to southeastern Tasmania, well-known for its ornamental appeal in cultivation and because of its rarity in the wild. The species is cultivated for its crown of silvery juvenile foliage in cooler climates in southeastern Australia, and particularly in southern Tasmania, as well as in overseas locations including the United Kingdom and New Zealand. The species has long been recognised as one of the rarer eucalypts (Pryor 1981) and is considered rare and inadequately reserved using the criteria of Briggs & Leigh (1996). While it does not qualify for listing under the *Tasmanian Threatened Species Protection Act 1995*, it is a Priority species for conservation under the Tasmanian Regional Forest Agreement.

Despite its naturally restricted distribution, *E. cordata* was first described by Jacques-Julien de Labillardière in 1806 from specimens he collected in 1793 while chief scientist aboard the French expedition ships *La Recherche* and *L'Espérance*. Potts (1988), in an historical account of the type locality of *E. cordata*, demonstrated that Labillardière certainly collected the type specimens from Penguin Island while the expedition was anchored in Adventure Bay off Bruny Island. Following the type collection, the species was rarely collected in the wild, despite being well-known from the Wellington Range area. Only in the past few decades has the species been more frequently collected and its distribution better known, mainly through the work of Potts (1988, 1989).

Population variation within *E. cordata* has been studied in detail by Potts (1989), although several more populations of the species have been discovered since that study at locations including the Meehan Ranges, Mount Hull and Kettering. In addition to a number of practical recommendations to conserve the genetic diversity in *E. cordata*, Potts (1989) proposed a taxonomic revision of the species and the recognition of two subspecies, which is formally adopted here. Subsequent flora treatments including the Tasmanian eucalypts have followed Potts (1989) in recognising the dimorphic and geographically-based variation within *E. cordata*, e.g., Williams & Potts (1996), Brooker & Kleinig (1999, 2006), Brooker *et al.* (2002), Nicolle (2006) and Slee *et al.* (2006).

Eucalyptus cordata is currently classified in *E.* ser. *Orbiculares* (Brooker 2000), which is distinguished within the genus by the combination of the following characteristics (amended from Brooker 2000):

E. subgen. Symphyomyrtus (Schauer) Brooker–cotyledons folded in seeds; flower buds bi-operculate; seeds with a ventral or terminal hilum; seed coat formed from both integuments.

E. sect. Maidenaria L.D. Pryor & L.A.S. Johnson ex Brooker–Cotyledons bilobed; inflorescences axillary; anthers versatile; seeds with a ventral hilum; adult leaves moderately reticulate and with island and intersectional oil glands.

E. subsect. Euryotae Brooker – Juvenile leaves sessile and opposite for many pairs; style long; adult leaves with oil glands; fruit disc and valves usually prominent.

E. ser. Orbiculares Brooker & Slee–Juvenile leaves orbicular, entire or broadly crenulate, usually waxy and opposite for many pairs (and often persistent in mature crown); mature crown often greyish; inflorescences 3-flowered; flower buds rhomboidal.

Brooker (2000) recognised ten species in *E.* ser. *Orbiculares*. The series is distributed in the cooler areas of southeastern Australia, from the Blue Mountains in the central tablelands of New South Wales southwards, with greatest taxonomic diversity in southeastern Tasmania. All but one species (*E. perriniana* F.Muell. ex Rodway) are endemic to either the Australian mainland or Tasmania.

Brooker (2000) included *E. chapmaniana* Cameron within *E.* ser. *Orbiculares*, but we do not include this species in the series here, preferring to include it in *E.* ser. *Viminales* Blakely (also with *E. smithii* R.T.Baker, *E. badjensis* Beuzev.

& M.B.Welch and *E. kartzoffiana* L.A.S.Johnson & Blaxell; these three species together forming *E.* ser. *Compactae* Brooker of Brooker 2000). *E. chapmaniana* differs from the remainder of *E.* ser. *Orbiculares* in the consistently forest tree habit, rough bark on the trunk, non-persistence of juvenile leaves (crown of lanceolate adult leaves), and small buds and fruits with a relatively broad, ascending disc. These characteristics are in common with other taxa of *E.* ser. *Viminales.*

Eucalyptus ser. *Orbiculares* can be further divided into two distinct groups (excluding *E. cordata*), namely, those taxa with sessile buds and fruits which occur on mainland Australia (with three of the four taxa endemic there), and those taxa with pedicellate buds and fruits which are endemic to Tasmania. *E. cordata* appears to fit most comfortably with the mainland taxa on morphological grounds, but the biogeography of the species suggests otherwise. Furthermore, a recent analysis of all Tasmanian taxa of *E.* sect. *Maidenaria* using multiple nuclear DNA markers (McKinnon *et al.* 2008) found that *E. cordata* was closely related to all other endemic Tasmanian species of *E.* ser. *Orbiculares*. None of these species was in the same genetic group as *E. perriniana* (the type species of *E.* ser. *Orbiculares*) which occurs both on mainland Australia and in Tasmania, raising the possibility that mainland and endemic Tasmanian taxa currently classified into *E.* ser. *Orbiculares* may represent different evolutionary lineages that have converged in morphology.

KEY TO THE TAXA OF *E.* SER. *ORBICULARES*

1. Buds and fruits sessile or nearly so 2
1. Buds and fruits pedicellate 7

2. Juvenile leaves connate..... *E. perriniana*
2. Juvenile leaves free 3

3. Mature crown composed of lanceolate, petiolate adult leaves 4
3. Mature crown composed mostly of rounded to ovate, sessile juvenile leaves 5

4. Fruits campanulate and with a flared rim .....
.....*E. saxatilis*
4. Fruits cupular to cylindrical and lacking a flared rim
..... *E. glaucescens*

5. Juvenile leaves firm, not cordate (rounded), 20–50 mm long; fruit 5–10 mm long ..... *E. pulverulenta*
5. Juvenile leaves lax, usually cordate, 15–95 mm long; fruit 7–13 mm long 6

6. Branchlets terete in transverse section .....
..... *E. cordata* subsp. *cordata*
6. Branchlets quadrangular in transverse section .....
.....*E. cordata* subsp. *quadrangulosa*

7. Peduncles long and down-curved; fruits urceolate ...
.....*E. urnigera*
7. Peduncles held erect; fruits cylindrical to barrel-shaped to slightly urceolate..... 8

8. Operculum slightly wider than hypanthium at join; coastal ..... *E. morrisbyi*
8. Operculum equal in width to hypanthium at join; alpine 9

9. All parts non-waxy; adult leaves green ... *E. archeri*
9. At least juvenile leaves waxy; adult leaves blue-green
..... 10

10. Fruits usually non-waxy and barrel-shaped .....
..... *E. gunnii* subsp. *gunnii*
10. Fruits waxy and barrel-shaped to urceolate .....
..... *E. gunnii* subsp. *divaricata*

TAXONOMY

Eucalyptus cordata Labill., *Nov. Holl. Pl.* 2, 13 (1806).

Type

"capite van-Dieman" [Van Diemens Land], *J.J.H. Labillardière s.n.* (holo: FI; iso: BM, G, L, MEL).

The type locality has commonly (and erroneously) been cited as Recherche Bay (near South East Cape), which appears to have stemmed from an erroneous citation of the species at Recherche Bay by Hooker (1860) and subsequent citations of the species at that locality by other authors until at least 1988 (Chippendale 1988). Potts (1988) demonstrated that Labillardière certainly collected the type specimens from Penguin Island, just off Bruny Island, where the species has been more recently verified (Potts 1988). The species has not been verified from Recherche Bay, with the nearest confirmed population being at Penguin Island, 45 km to the northeast.

Description

Scraggy shrub or tree up to 25 m tall, usually several to multi-stemmed. Lignotuber present. Bark usually smooth throughout, grey to orange-tan over pale grey to tan, decorticating in strips and ribbons. Rough bark sometimes present on the lower trunks of larger trees (in subsp. *quadrangulosa*), moderately fissured, grey. Branchlets lacking pith glands. Branchlets, leaves, flower buds and fruits waxy, at least when young. Plant usually reproductively mature in juvenile leaf phase. Juvenile leaves amplexicaul, free (not connate), broadly crenulate (scalloped) or sometimes entire, waxy, dull, greyish. Inflorescences axillary, unbranched, held erect, 3-flowered. Operculum scar present. Stamens mostly inflexed, all fertile; anthers cuboid to oblong, versatile, dorsifixed, dehiscing by longitudinal slits. Ovules in 4–6 vertical rows. Flowers white. Seeds grey to black, compressed ovoid, finely lacunose.

Discussion

Eucalyptus cordata is distinguished within *E.* ser. *Orbiculares* by the following combination of characters: plant reproductively mature in juvenile leaf phase and rarely producing adult leaves; branchlets, leaves, buds and fruits waxy, at least while young; juvenile leaves free (not connate), often broadly crenulate (scalloped); inflorescences pedunculate and held erect; pedicels absent or to 2 mm long; fruits (truncate-globose to) cupular (to shortly barrel-shaped).

Two geographically disjunct subspecies are recognised in *E. cordata*, differing from one another most notably in branchlet morphology, but also in habit characteristics and vegetative and reproductive morphology. Little weight has been placed on habit differences in the recognition of the two subspecies. There is a large degree of overlap in habit characteristics between the two subspecies, and habit is likely to be at least partly environmentally determined within the species, with varying site conditions and fire histories at each population. In addition to the morphological distinctions, the two subspecies also differ in habitat preferences and flowering times. A few populations suspected to be intergrades between the two subspecies are known in geographically intermediate regions and are described below. Neither subspecies of *E. cordata* has been confirmed from Meredith Tier (near Swansea; north of the verified distribution of *E. cordata*), and hybrid swarms involving *E. barberi* L.A.S.Johnson & Blaxell from this locality most likely involve *E. gunnii* Hook.f. (McEntee *et al.* 1994), which occurs approximately 7 km away (Potts 1988).

Representative photographs of the branchlets, leaves, buds and fruits of the two subspecies, which readily illustrate the morphological differences between them, can be found in Potts (1989), Williams & Potts (1996), Nicolle (2006) and Wiltshire & Potts (2007).

Eucalyptus cordata Labill. subsp. *cordata*

Distinguished from subsp. *quadrangulosa* most conspicuously by the terete branchlets (pl. 1; square to winged in transverse section in subsp. *quadrangulosa*), and also in the consistently scraggy under-shrub habit, smaller and more rounded juvenile leaves, the terete or less prominently flattened peduncles, the smaller non-ribbed flower buds, and the smaller fruits.

Description

Scraggy shrub up to 6 m tall, usually multi-stemmed; often growing as an understorey shrub to taller forest or woodland eucalypt species (pl. 2). Branchlets rounded in transverse section, often conspicuously minutely warty, variably waxy. Juvenile leaves opposite, sessile and amplexicaul, cordate to rounded, usually entire, (15–) 30–70 (–80) mm long x (15–) 25–60 (–70) mm wide, variably waxy, slightly discolorous to concolorous, dull, grey-green. Intermediate leaves opposite to sub-opposite, petiole to 12 mm long, lamina ovate, longer and relatively narrower than juvenile leaves. Adult leaves rarely developed, sub-opposite, petiole to 15 mm long, lamina lanceolate, to 90 mm long, variably waxy, concolorous, dull, grey-green. Peduncles 2–12 (–15) mm long, terete to slightly flattened. Pedicels absent or to 2 mm long (especially the middle bud/fruit), terete to angular. Flower buds 7–11 mm long x 4.5–7 mm wide, waxy; hypanthia cupular; opercula smooth, rounded to pileate, 2.5–5 mm long. Fruits cupular to shortly barrel-shaped, 7–10 (–11) mm long x 6–10 (–12) mm wide, waxy at first; disc descending; valves 3 or 4, to rim level.

Specimens examined

TASMANIA: 1 km NW of Jacob Hill, Sandpit River area, undated, *S. Harris s.n.* (HO); Brown Mountain [probably Mount Brown], Port Arthur, Sept. 1937, *R.G. Brett s.n.* (HO) [*E. cordata* has not been found on Mount Brown

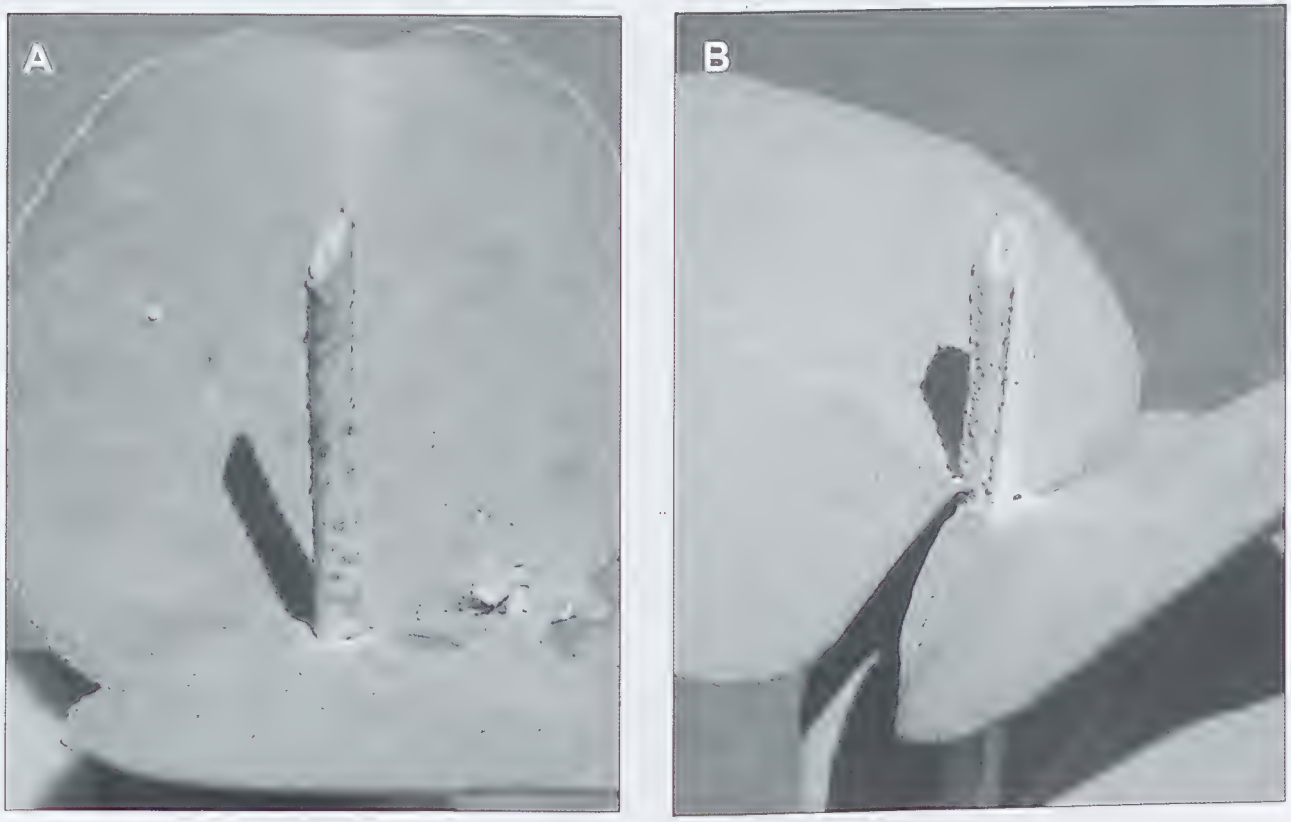


PLATE 1

Branchlets from cultivated eight-year-old Eucalyptus cordata *growing at Currency Creek Arboretum, South Australia. (A) Subsp.* cordata, *F1 of D. Nicolle 1985 collected from SE of Nugent, 42°45'13"S, 147°49'28"E. (B) Subsp.* quadrangulosa, *F1 of D. Nicolle 1979 collected from Mt Lloyd, SW of New Norfolk, 42°50'11"S, 146°56'54"E.*

PLATE 2
Habit and habitat of Eucalyptus cordata *subsp.* cordata *(Hospital Creek, north of Kellevie). Note that* E. cordata *is the very low scraggy shrubs in the centre foreground; larger eucalypts in the background are mainly* E. pulchella, *with some* E. globulus *and* E. obliqua.

despite extensive searching – Potts 1989 – and this locality is either an erroneous rendering of Brown Mountain near Runnymede, where *E. cordata* aff. ssp. *cordata* is known to occur, or the population is now extinct]; Nelsons Tier, Feb. 1941, *R.G. Brett s.n.* (HO); Summerleas Road, Sept. 1942, *R.G. Brett s.n.* (HO); banks of Prosser River, on hill, May 1945, *R.G. Brett s.n.* (HO); Wielangta, May 1945, *R.G. Brett 10* (HO); SE Maria Island. Near (slopes of) Perpendicular Mountain, April 1976, *A. Moscal s.n.* (HO); Trig Point, Hellfire Bluff, 3 Nov. 1979, *M.J. Brown 497* (HO); Maria Island, Perpendicular Mountain, 18 June 1979, *A. Moscal 55* (AD); Chimney Pot Hill, on telecom access rd, 2 km from Ridgeway Rd junction, 9 Jan. 1980, *A.M. Grey 471* (HO); Hospital Creek, 28 Nov. 1980, *F. Duncan s.n.* (HO); Burdens Razorback, N of Kellevie, 31 Oct. 1983, *A. Moscal 3861* (HO); Cape Queen Elizabeth, North Bruny Island, 31 March 1986, *A.M. Buchanan 8379* (CANB, HO, MEL, NSW); Penguin Island, on S cliff slope (facing Fluted Cape), Nov. 1986, *B.M. Potts PI4, PI5, PI7, PI8 & PI9* (HO); Pony Bottom Creek, 18 Dec. 1987, *B. Potts s.n.* (HO); Back Run Hills, 12 August 1993, *B. Warren s.n.* (HO); Meehan Range, above mudstone cliffs at end of track branching from main ridge road, 21 Sept. 1997, *B. Potts s.n.* (CANB, HO, NSW); Meehan Range, SRA – Redgate Section, 8 August 1996, *K. Ziegler s.n.* (HO); SE of Nugent, 42°45'13"S, 147°49'28"E, 24 Feb. 1997, *D. Nicolle 1985* (AD, CANB); Hellfire Bluff, 27 Sept. 2003, *K. Felton s.n.* (HO); summit of Perpendicular Mountain, Maria Island, 11 Oct. 2003, *K. Felton s.n.* (HO); Penguin Island, off Grass Point, South Bruny Island, 28 Feb. 2004, *A.M. Grey 1338* (HO); hill just S of Whittens Road, S of Kettering, 21 Dec. 2004, *A. Welling s.n.* (HO); Ragged Tier, N of Bream Creek, 42°47'32"S, 147°50'44"E, 7 May 2005, *D. Nicolle 4931* (AD).

Distribution and habitat

Endemic to southeastern Tasmania, where it occurs east from Mt Grosse near Middleton and south from Bluestone Tier near Triabunna, including Bruny and Maria islands and the Tasman Peninsula, over a maximum linear range of 110 km (fig. 1).

Eucalyptus cordata subsp. *cordata* is known from approximately 27 very scattered populations. The subspecies grows from near sea level to 470 m altitude in dry or seasonally drought-stressed sclerophyll forest, woodland or coastal scrub, on moderately well-drained skeletal clay-loams, often as an under-storey shrub to larger eucalypt species such as *E. globulus* Labill., *E. obliqua* L'Her., *E. viminalis* Labill. and most commonly *E. pulchella* Desf. (pl. 2). In coastal sites the subspecies may occur in small, near pure stands or with *Allocasuarina verticillata* (Lam.) L.A.S.Johnson. The subspecies tends to occur at lower altitudes having a lower and less reliable rainfall and on better-drained soils than those occupied by subsp. *quadrangulosa.*

An atypical population of *E. cordata* subsp. *cordata* occurring on Brown Mountain near Runnymede develops adult foliage and may have some affinities to *E. urnigera* Hook.f. (Potts 1988). The population occurs on a poorly drained site at relatively high altitude (710 m) near an outlying population of *E. coccifera* Hook.f. (Potts 1989), a habitat otherwise atypical for *E. cordata* subsp. *cordata.*

Conservation status

Approximately 27 populations consisting of an estimated 4000–5000 individual plants are known. The largest populations occur at Corbetts Lookout (near Kellevie – c. 1000 individuals), Cape Queen Elizabeth (Bruny Island – c.1000 individuals) and Perpendicular Mountain (Maria Island – 500+ individuals), while most populations generally have less than several hundred individual plants (Potts 1988, 1989).

Six populations occur in reserves, namely, the populations at Perpendicular Mountain (Maria Island National Park), Hellfire Bluff (Cape Bernier State Reserve), Hospital Creek (Hospital Creek Nature Reserve), Meehan Range (Meehan

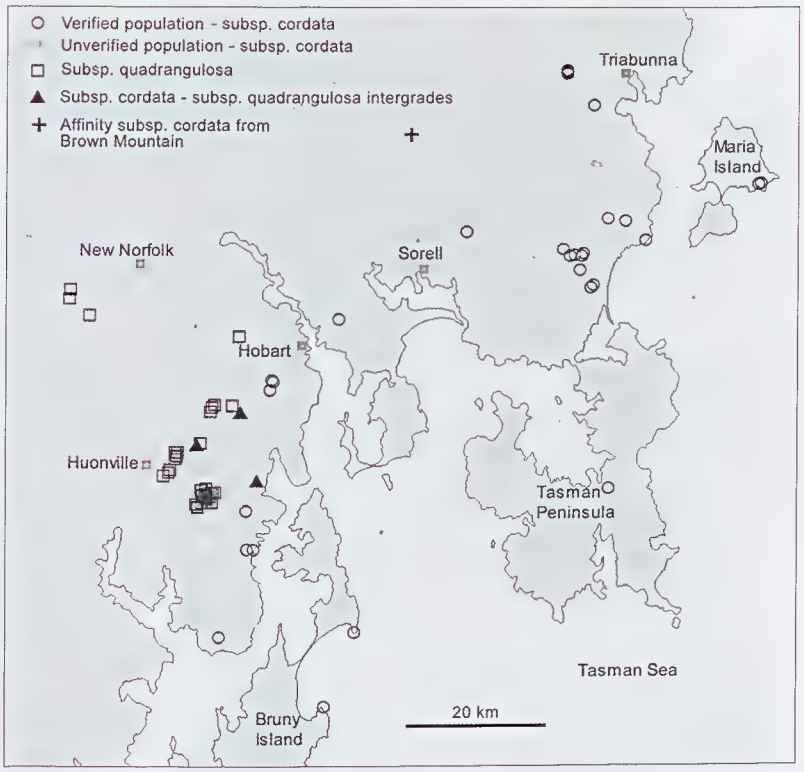


FIG. 1— Map of southeastern Tasmania, indicating the distribution of Eucalyptus cordata.

Range National Recreation Area), Cape Queen Elizabeth (Bruny Island Neck Game Reserve) and Penguin Island (South Bruny National Park). Other populations occur in state forest or on privately-owned land.

Discussion

Eucalyptus cordata subsp. *cordata* is most readily distinguished from the Tasmanian endemics *E. archeri* Maiden & Blakely, *E. gunnii, E. morrisbyi* Brett and *E. urnigera* by the retention of largely juvenile leaves in the mature crown, although a number of other vegetative and reproductive morphological characteristics also distinguish *E. cordata* subsp. *cordata* from these taxa. From *E. perriniana* (the only *E.* ser. *Orbiculares* taxon to occur naturally both on the mainland and in Tasmania), *E. cordata* subsp. *cordata* differs most conspicuously in the non-connate juvenile leaves forming the crown of the plant. *E. cordata* subsp. *cordata* may be confused with the mainland species *E. pulverulenta* Sims, which occurs as a few very scattered populations between Lithgow and Bombala in New South Wales. *E. cordata* subsp. *cordata* differs from *E. pulverulenta* in the generally larger, more lax, cordate, and often broadly crenulate (scalloped) juvenile leaves, the usually warty juvenile branchlets, and the fruits with a more descending disc and less exsert valves.

A hybrid swarm involving *E. cordata* subsp. *cordata* and another eucalypt, putatively *E. barberi*, has been recorded at the Pony Bottom Creek population of the former, at the northern end of its distribution (Potts 1989, McEntee *et al.* 1994). Populations of *E. cordata* subsp. *cordata* at Prosser River and Hellfire Bluff may have genetic introgression from surrounding *E. viminalis*, as indicated by seedling studies (Potts 1989).

Eucalyptus cordata subsp. *quadrangulosa* D. Nicolle, B.M. Potts & G.E. McKinnon *subsp. nov.*

= *Eucalyptus cordata* subsp. "western" (Nicolle 2006: 106).

Type

Snug Plains, 15 April 1979, *A.M. Grey 357* (holo: HO; iso: CANB) (pl. 3).

A subspecie typica ramuli quadrangulatis, foliis juvenilibus majoribus et plus acutis, pedunculis plus saepissime applanatis, alabastris fructibusque bialatis et majoribus differt.

Distinguished from the typical subspecies most conspicuously by the quadrangular branchlets (pl. 1), and also in the commonly larger habit, the larger and more pointed juvenile leaves, the more commonly flattened peduncles, the larger bi-ribbed flower buds, and the larger bi-ribbed fruits.

Description

Bushy shrub or tree, often several-stemmed, 2–25 m tall (pl. 4). Branchlets quadrangular to 4-winged in transverse section, usually waxy. Juvenile leaves opposite, sessile and amplexicaul, cordate to ovate to broadly elliptical, entire to broadly crenulate (30–) 45–90 (–100) mm long x (35–) 40–65 (–95) mm wide, usually waxy, slightly discolorous to concolorous, dull, grey-green. Intermediate leaves subopposite, becoming petiolate, lamina elliptical to ovate, longer and relatively narrower than juvenile leaves. Adult leaves occasionally developed in taller trees, disjunct, petiole to 30 mm long, lamina lanceolate, to 180 mm long x 70 mm wide, variably waxy, concolorous, dull, grey-green. Peduncles 5–12 mm long, angular to flattened. Pedicels absent or to 1 mm long (especially the middle bud/fruit). Flower buds 10–12 (–13) mm long x 7–10 mm wide, waxy; hypanthia cupular,

PLATE 3
Holotype of Eucalyptus cordata *subsp.* quadrangulosa *(A.M. Grey 357).*

usually bi-ribbed; opercula smooth, pileate, 2–5 mm long. Fruits cupular to truncate-globose, usually bi-ribbed, 10–12 (–13) mm long x 11–14 (–15) mm wide, waxy at first; disc broad, descending; valves rarely 3, usually 4, to rim level.

Specimens examined

TASMANIA: Mount Lloyd, Feb. 1941, *R.G. Brett s.n.* (HO); Mount Lloyd, Aug. 1942, *R.G. Brett s.n.* (HO); ridge, E of Huonville, May 1945, *R.G. Brett s.n.* (HO); Herringback, Dec. 1952, *W.D. Jackson s.n.* (HO); Snug Plains, Margate, Dec. 1952, *W.D. Jackson s.n.* (HO); Betts Road, NW side of North West Bay River, 1 Aug. 1959, *W.D. Jackson s.n.* (HO); Moogara area, 1.3 km W of old house on road 3.2 km from Uxbridge – Moogara junction towards New Norfolk, 13 Nov. 1974, *G. Chippendale* 1192 & *A.M. Grey* (AD, CANB); Moogara, 24 Nov. 1977, *M.I.H. Brooker 5779* (AD, HO, MEL, NSW); 13 km SW of Glenora Road on road to Mt Lloyd. 100 m S of junction of road and Leesons Creek, 19 Dec. 1977, *J.D. Briggs 84* (HO); Leslie Rd, 0.5 km from junction with Huon Road. Between road and the Levert Rivulet, 3 Jan. 1980, *A.M. Grey 458* (CANB, HO); Leslie Rd, 0.5 km from junction with Huon Road. Between road and the Levert Rivulet, 3 Jan. 1980, *A.M. Grey 459* (CANB, HO, MEL); Sherwood Hill, 12 Dec. 1988, *B. Potts s.n.* (HO); on slopes north of Knights Creek, 1200 m SE of Mt Hull, 15 Dec. 1996, *R.B. Schahinger s.n.* (HO); Hoopers Hill, Moogara, 10 Feb. 1994, *N. McCormick s.n.* (HO); Mt Lloyd, SW of New Norfolk, 42°50'12"S, 146°56'54"E, 24 Feb. 1997, *D. Nicolle 1979* (AD, CANB); top of Pelverata Falls, Snug Tiers State Forest, 6 July 1999, *A.C. Rozefelds 1405* (HO); Mt Lloyd, SW of New Norfolk, 42°50'12"S, 146°56'54"E, 8 May 2005, *D. Nicolle 4940* (AD); foot of Herringback, 43°00'18"S, 147°08'44"E, 25 March 1997, *A.M. Buchanan 14505* (HO); Lesley Vale Road, c. 1 km from Huon road junction, 29 Jan. 1981, *A.M. Grey 543* (AD).

PLATE 4
Habit and habitat of Eucalyptus cordata *subsp.* quadrangulosa *(Mt Lloyd, SW of New Norfolk, D. Nicolle 4940).*

Distribution and habitat

Endemic to southeastern Tasmania, and centred in the Wellington Range area, extending northwest to Mt Lloyd and Moogara and south to Snug Plains. The subspecies is most prolific on Snug Plains, but is also known from approximately nine populations elsewhere, over a maximum linear range of approximately 45 km (fig. 1).

Eucalyptus cordata subsp. *quadrangulosa* grows in subalpine sites (400–700 m altitude) in wet sclerophyll forest on poorly-drained clay-loams, often on the margins of largely treeless swampy sites dominated by *Leptospermum sp.* (tea tree) or *Gahnia grandis* (sedge grass) (pl. 4). Associated eucalypts include *E. dalrympleana, E. delegatensis, E. globulus, E. johnstonii, E. obliqua, E. regnans* and *E. urnigera.* The subspecies tends to occur at higher altitudes having a higher and more reliable rainfall and on more poorly-drained soils than those occupied by subsp. *cordata.*

Conservation status

Approximately ten populations consisting of at least 7000 individual plants are known. The Snug Plains population is the most extensive, consisting of at least 5000+ individuals (Potts 1988, 1989), while the northwestern Mt Lloyd and Moogara populations each consist of less than a few hundred individuals.

Eucalyptus cordata subsp. *quadrangulosa* is poorly conserved compared to subsp. *cordata*, despite total numbers of the former being greater. Most populations occur on privately-owned land, and the most extensive populations on Snug Plains occur in state forest.

Etymology

The subspecific epithet is from the Latin *quadrangulosus* (four-cornered), referring to the quadrangular (square in cross-section) branchlets, which most readily distinguish the new subspecies within the species. The quadrangular branchlets are also unique in *E.* ser. *Orbiculares.*

Discussion

In addition to the morphological distinctions, the two subspecies of *E. cordata* differ in habitat preferences and phenology. *E. cordata* subsp. *quadrangulosa* tends to occur at higher altitudes having a higher and more reliable rainfall and on more poorly drained soils than subsp. *cordata.* Cultivation trials of the two subspecies under uniform conditions (Nicolle 2003, Potts 1989) indicate that the morphological differences between the two subspecies are genetically determined and not related to these environmental variables. Flowering in wild populations of subsp. *quadrangulosa* occurs mainly in spring (cf. subsp. *cordata* in autumn and winter). Flowering times in cultivation have not been studied.

The quadrangular stems characteristic of *E. cordata* subsp. *quadrangulosa* are unique within *E.* ser. *Orbiculares*, but are a common and conspicuous feature of the juvenile stems of other taxa within *E.* sect. *Maidenaria*, including *E.* ser. *Semiunicolores* Blakely (five or six taxa, including *E. johnstonii*) and *E.* ser. *Globulares* Blakely (c. 16 taxa, including *E. globulus*), as well as occurring in some taxa in all other sections in the genus. The occurrence of quadrangular stems and other characteristics in subsp. *quadrangulosa* that diagnose the subspecies from subsp. *cordata* may be due to past genetic introgression from a quadrangular-stemmed *E.* sect. *Maidenaria* taxon. Both *E. globulus* and *E. johnstonii* Maiden occur sympatrically with *E. cordata* subsp. *quadrangulosa* at some localities, and indeed natural hybrids and hybrid swarms involving *E. cordata* subsp. *quadrangulosa* and *E. johnstonii*, and a putative *E. cordata x E. globulus* hybrid, have been recorded (Potts 1989). A detailed comparison of chloroplast DNA variation across the full ranges of *E. globulus* and *E. cordata* (McKinnon *et al.* 2004) also supports past, recurrent gene flow between *E. globulus* and both subsp. *quadrangulosa* and *cordata* at different mixed populations. However, the possibility of parallel evolution of the quadrangular stem within different series cannot be dismissed.

Eucalyptus cordata subsp. *quadrangulosa* is often cultivated in Tasmania and occasionally in the cooler and higher-rainfall parts of southeastern mainland Australia, where it is grown as an ornamental bushy tree for its crown of persistent greyish or silvery juvenile foliage. *E. cordata* subsp. *quadrangulosa* is also known to be cultivated in New Zealand. This subspecies appears to be more susceptible to seasonally dry conditions in cultivation compared to the rarely cultivated subsp. *cordata.*

Intermediates between the subspecies

The two subspecies are geographically divided longitudinally, and for the most part occupy different altitudes. There is no indication of a clinal trend in stem shape with altitude, and when the atypical high-altitude population of subsp. *cordata* at Brown Mountain is excluded, the change in stem shape is stepped with an abrupt change between 400 and 500 m altitude. A few populations containing notable frequencies of individuals with variable and/or intermediate stem shape occur at the distributional boundary (fig. 1) at both low and high altitudes. The population at Electrona (140 m altitude) currently contains individuals with affinities to both subspecies, with a higher frequency of subsp. *cordata*, while the Leslie Road population (250 m) contains approximately equal numbers of the two subspecies, and some individuals of intermediate morphology. The population on the summit of Herringback (680 m) was recorded by Potts (1989) as being predominantly but not exclusively subsp. *quadrangulosa.* Other intermediate specimens may be found at low frequency in other populations.

ACKNOWLEDGEMENTS

The first author wishes to thank Sally-Anne Davis and Bob Nicolle for accompaniment on field trips in southern Tasmania and Bob Chinnock (State Herbarium of South Australia) and staff at the Tasmanian Herbarium for organising loan material of *E. cordata.*

REFERENCES

Briggs, J.D. & Leigh, J.H. 1996: *Rare or Threatened Australian Plants.* CSIRO, Australia: 466 pp.

Brooker, M.I.H. 2000: A new classification of the genus *Eucalyptus* L'Her. (Myrtaceae). *Australian Systematic Botany* **13**: 79–148.

Brooker, M.I.H. & Kleinig, D.A. 1999: *Field Guide to Eucalypts Vol. 1. South-eastern Australia.* Second Edition. Bloomings Books, Melbourne: 353 pp.

Brooker, M.I.H. & Kleinig, D.A. 2006: *Field Guide to Eucalypts Vol. 1. South-eastern Australia.* Third Edition. Bloomings

Books, Melbourne: 356 pp.

Brooker, M.I.H., Slee, A.V., Connors, J.R. & Duffy, S.M. 2002: *Euclid, Eucalypts of Southern Australia.* Second Edition. CSIRO Publishing, Australia. CD Rom.

Chippendale, G.M. 1988: *Eucalyptus, Angophora. In* A.S. George (ed.): *Flora of Australia.* Volume 19, Myrtaceae - *Eucalyptus, Angophora.* Australian Government Publishing Service, Canberra: 370–371.

Hooker, J.D. 1860 *The Botany of the Antarctic Voyage of H.M. Discovery Ships Erebus and Terror in the years 1830–1843, under the Command of Captain Sir James Clark Ross.III. Flora Tasmaniae.* Lovell Reeve, London: 781 pp.

McEntee, A.C., Potts, B.M. & Reid, J.B. 1994: Variation in *Eucalyptus barberi* L. Johnson & Blaxell. *Papers and Proceedings of the Royal Society of Tasmania* **128**: 21–30.

McKinnon, G.E., Vaillancourt, R.E., Steane, D.A. & Potts, B.M. 2004: The rare silver gum, *Eucalyptus cordata,* is leaving its trace in the organellar gene pool of *Eucalyptus globulus. Molecular Ecology* **13**: 3751–3762.

McKinnon, G.E., Vaillancourt, R.E., Steane, D.A. & Potts, B.M. 2008: An AFLP marker approach to lower-level systematics in *Eucalyptus* (Myrtaceae). *American Journal of Botany* **95**: 368–380.

Nicolle, D. 2003: *Currency Creek Arboretum Eucalypt Research.* Vol. 2. D. Nicolle, Adelaide: 81 pp.

Nicolle, D. 2006: *Eucalypts of Victoria and Tasmania.* Bloomings Books, Melbourne: 310 pp.

Potts, B.M. 1988: The distribution and type locality of *Eucalyptus cordata* Labill. – an historical account. *Papers and Proceedings of the Royal Society of Tasmania* **122**(2): 31–38.

Potts, B.M. 1989: *Population Variation and Conservation Status of the Rare Tasmanian Endemic,* Eucalyptus cordata. Tasmanian Forest Research Council Inc., Hobart, Tasmania: 140 pp.

Pryor, L.D. 1981: *Australian Endangered Species: Eucalypts.* Special Publications No. 5. Australian National Parks and Wildlife Service: 140 pp.

Slee, A.V., Brooker, M.I.H., Duffy, S.M. & West, J.G. 2006: *Euclid, Eucalypts of Australia.* Third Edition. CSIRO Publishing, Australia: CD Rom.

Williams, K.J. & Potts, B.M. 1996: The natural distribution of *Eucalyptus* species in Tasmania. *Tasforests* **8**: 39–165.

Wiltshire R. & Potts B. 2007: *EucaFlip.* School of Plant Science, University of Tasmania and Cooperative Research Centre for Forestry: Pamphlet sheet.

(accepted 1 April 2008)

ECOLOGICAL OBSERVATIONS AND NEW LOCATIONS OF A RARE MOSS, *AMBUCHANANIA LEUCOBRYOIDES* (AMBUCHANANIACEAE)

by K. A. Johnson, J. Whinam, A. M. Buchanan and J. Balmer

(with one text-figures, three plates, two tables and one appendix)

Johnson, K.A., Whinam, J., Buchanan, A.M. & Balmer, J. 2008 (28:xi): Ecological observations and new locations of a rare moss, *Ambuchanania leucobryoides* (Ambuchananiaceae). *Papers and Proceedings of the Royal Society of Tasmania* 142(2): 79–84. ISSN 0080-4703. Biodiversity Conservation Branch, Department of Primary Industries and Water, GPO Box 44, Hobart, Tasmania 7001, Australia.(KAJ, JW*, AMB, JB). *Author for correspondence. Email: Jennie.Whinam@dpiw.tas.gov.au

Ambuchanania leucobryoides is a moss listed as rare under the Tasmanian *Threatened Species Protection Act 1995.* It is endemic to Tasmania and is monotypic at the genus and family levels. It is sister group to the widespread and speciose genus *Sphagnum.* In 2008, a survey funded by the Tasmanian Wilderness World Heritage Area Program (Australian Government Department of the Environment, Water, Heritage and the Arts) established the exact location of the *A. leucobryoides* type locality and extended the known range of the moss. The moss is now known from three locations in southwest Tasmania and has a linear range of 127 km. It occurs in sandy washes or "daisy pans" derived from Precambrian quartzite.

Key Words: threatened species, moss, Ambuchananiaceae, southwest Tasmania, monotypic, *Ambuchanania leucobryoides.*

INTRODUCTION

The moss *Ambuchanania leucobryoides* (T. Yamag., Seppelt & Z. Iwat.) Seppelt & H. A. Crum is endemic to Tasmania, Australia. First described in the genus *Sphagnum* (Yamaguchi *et al.* 1990), it was included in the Tasmanian moss flora under that name (Dalton *et al.* 1991). Its present taxonomic status in the monotypic genus *Ambuchanania* and monotypic family Ambuchananiaceae recognises its isolated position within the class Sphagnopsida (Crum & Seppelt 1999, Seppelt 2000). The class Sphagnopsida comprises two genera: *Ambuchanania* and *Sphagnum* (Shaw 2000, Shaw *et al.* 2003). The latter is one of the most widespread genera of mosses, extending from the Arctic through to sub-Antarctic Macquarie Island (Moore & Bellamy 1974). *A. leucobryoides* was listed as rare under the Tasmanian *Threatened Species Protection Act 1995* in 2003.

Ambuchanania leucobryoides was first collected in 1987 by A. Buchanan, in a remote part of the Tasmanian Wilderness World Heritage Area (Wallaby Bay near Davey Head).

The aims of the present study were to relocate the type locality (a small sandy wash near Wallaby Bay), document the habitat and plant species occurring with it and improve the knowledge of its distribution by conducting extension surveys. *A. leucobryoides* is of international interest; researchers from the University of London and Duke University requested, and were supplied with, a collection of stems for the establishment of axenic cultures that will be used in research including the interpretation of moss phylogenies.

METHODS

On 3 March 2008, the Tasmanian Wilderness World Heritage Area Program conducted a helicopter expedition to the *A. leucobryoides* type locality at Wallaby Bay. Habitat with a similar appearance to the type locality was located by helicopter and a further three sites were inspected for the presence of *A. leucobryoides.* Brief searches were undertaken on foot in sandy habitat along the lower slopes of the Bathurst Range and in sandy habitat adjacent to the Cox Bight to Melaleuca walking track (5 March 2008); along McKays track from Scotts Peak to Junction Creek and Arthur Plains just beyond Junction Creek (9 April 2008); and at the base of the Sentinel and Twelvetrees Ranges (14 May 2008). Penny Tyson (Wildcare Volunteer) undertook a search in the Birchs Inlet area (19 March 2008).

The only other *A. leucobryoides* collection held at the Tasmanian Herbarium (HO) was reported to be from the Adelaide River, near the Jane River track (over 100 km from the type locality and over 60 km inland). Few habitat details were available for this record as the moss was located amongst the roots of a sedge, *Isolepis aucklandica* Hook.f., (HO 3450) (Crum & Seppelt 1999). A helicopter trip and foot search was undertaken along the Jane River track from near the Adelaide River to the Lyell Highway (16 April 2008).

Environmental information on the southwest Tasmania study area including the geology, soils and climate was gathered from various published sources and field observations. A soil sample was taken from the *A. leucobryoides* type locality at Wallaby Bay and analysed at Allison Laboratories (Hobart, Tasmania) for exchangeable nitrogen, organic content, pH, conductivity, and the nutrients: phosphorous, nitrogen, potassium, sodium, calcium and magnesium. The pH of a soil sample from Birchs Inlet was taken using an Inoculo Laboratories Australia Soil pH Test Kit. Vascular and non-vascular plant species were recorded at *A. leucobryoides* sites. Vascular plant nomenclature follows Buchanan (2007) and non-vascular follows Streimann & Klazenga (2002) for mosses and McCarthy (2003) for liverworts. A permanent-monitoring site was established at Wallaby Bay. All collections were made under a permit and authority issued under provisions of the *Threatened Species Protection Act 1995* and the *National Parks and Wildlife Act 1970.*

RESULTS

Distribution and habitat

Ambuchanania leucobryoides was relocated at the type locality at Wallaby Bay in March 2008. It was originally recorded from only one point location but is now known from numerous sandy pans both north and south of Coffin Creek. There is approximately one kilometre between the furthest sites observed in this brief and localised survey. Further extension surveys carried out at this time located the moss near Swallow Creek, Louisa Bay, 38 km southeast of the Wallaby Bay site. It was also found near Birchs Inlet (south of Macquarie Harbour), 90 km north of the Wallaby Bay site and up to 5 km inland from Birchs Inlet. However, the species was not observed in the sandy washes between Cox Bight and Melaleuca. These were observed to be generally of coarser gravel rather than the finer sand of the Wallaby Bay site.

Ambuchanania leucobryoides was not found in brief searches that were carried out in two washes on the eastern low slopes of Mt Rugby, near Eds Cove (despite the presence of fine sand) and at the base of the Bathurst Range, behind Cox Bight. *A. leucobryoides* was not found along McKays track, Arthur Plains near Junction Creek, or at the base of the Sentinel or Twelvetrees ranges. The habitat in these areas is quite different from the near coastal environment of Wallaby Bay with black organic soils and no white sandy washes. If sand was present it was a covering of surface sand only. Alex Buchanan and Tony Moscal (Tasmanian Herbarium) have undertaken many collecting trips in southwest Tasmania (before and since 1987) and have not observed this species more widely.

Ambuchanania leucobryoides was not found in moorland near the Adelaide River or at other locations searched along the Jane River track. Its absence and the difference in habitat from the type locality (black organic soils rather than fine white sandy washes) prompted the original identification of the specimen, as *A. leucobryoides,* to be re-examined. It has now been redetermined as *Sphagnum novozelandicum* Mitt. (Rod Seppelt pers. comm. 2008).

Ambuchanania leucobryoides is currently known from three locations in the warm perhumid climate of southwest Tasmania: Wallaby Bay at Port Davey on the southwest coast; Swallow Creek near Louisa Bay on the south coast; and Birchs Inlet, south of Macquarie Harbour (fig. 1). The linear range of the species is 127 km and the altitude is 20–50 m above sea level. The species is most likely restricted to Precambrian quartzite sandy washes (pl. 1). Across this range the mean maximum temperature is about 16°C and the mean minimum about 9°C. The hottest month is February and the coldest period is July to August. The mean rainfall is about 1450 mm and falls on an average of 192 days (Bureau of Meteorology 2008 – annual figures averaged from the closest weather station to Wallaby Bay and Swallow Creek (Maatsuyker Island Lighthouse) and Birchs Inlet (Vivian St, Strahan)). Collections of *A. leucobryoides* were made at each location and specimens were lodged in the Tasmanian Herbarium (HO). A small number of stems were sent to researchers at the University of London for axenic cultures (these cultures will be made available to scientists worldwide for DNA studies) and cryopreservation in the Millenium Seed Bank (Prof. J. Duckett pers. comm.). Jon Shaw, Duke University, has previously examined the molecular genetics from the holotype specimen in Hiroshima and has also received fresh material from the present collection for further molecular genetic analysis. Field data have been entered into the Natural Values Atlas (Department Primary Industries and Water).

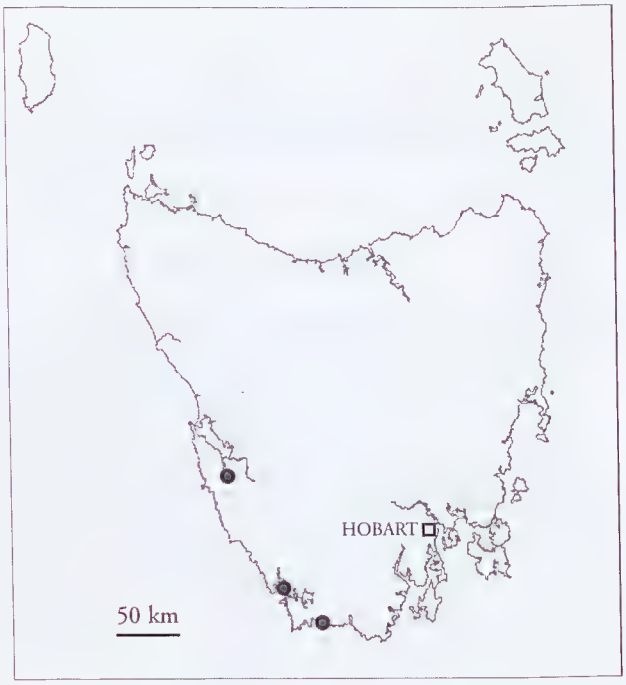


FIG. 1 — Distribution of Ambuchanania leucobryoides *in Tasmania.*

Identification

Ambuchanania leucobryoides was originally described as *Sphagnum leucobryoides* due to its similarities to that genus (Yamaguchi *et al.* 1990). The description provides morphological details and illustrations not repeated here. Seppelt (2000) provides a key to the Australian Sphagnopsida that separates *Ambuchanania* from *Sphagnum.* In the field, the shoot tips of *A. leucobryoides* are almost flush with the ground surface, the tips of the uppermost leaves are generally the only parts showing above ground, giving the sandy surface a spotted appearance - like "measles" (pls 2, 3). *A. leucobryoides* is distinguished from *Sphagnum* as follows (Crum & Seppelt 1999):

- notably whitish and glossy, dry character;
- leaves are unusually large, the stem leaves up to 4.3 mm long and those at the ends of the short branches up to 8.6 mm long; the internal arrangement of chlorocysts and hyalocysts is quite different;
- capsules are produced singly in the terminal position (at the ends) of the stems.

Geomorphology and soil composition

The *A. leucobryoides* habitat at Wallaby Bay is a series of nearly flat, alluvial sand pans or washes consisting almost entirely of white, fine-grained, quartzitic sand. These washes occur in the undulating near-coastal landscape dominated by buttongrass (*Gymnoschoenus sphaerocephalus* (R.Br.) Hook.f.) moorland. At Wallaby Bay the sandy soil is derived from Precambrian quartzite and is of very low nutrient status (Yamaguchi *et al.* 1990). The soil sample collected from the type locality is likely to have been derived from the local catchment and

PLATE 1
The sandy wash of the Ambuchanania leucobryoides *habitat stands out from surrounding vegetation. Photo: J. Whinam.*

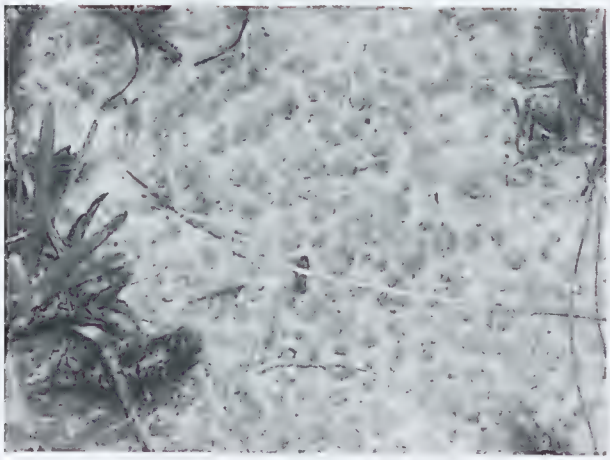


PLATE 2
In the field, Ambuchanania leucobryoides *is recognised by spots (or "measles") on the sand surface. It is densely distributed in this photo. Photo: J. Whinam.*

PLATE 3
Ambuchanania leucobryoides *sparsely distributed and largely covered by sand. Photo: J. Whinam.*

transported only a short distance by overland flow or small streams (Ian Houshold pers. comm. 2008). The pH of the sandy soil sample from the type locality (pH 6.8) and from Birchs Inlet (pH 6) is close to neutral (table 1) — well above that of the 4.1–4.4 of organosols (peaty soils) on Precambrian quartzite till (Bowman *et al.* 1986). It is also well above the pH of 3.4–3.5 for soils associated with "buttongrass moorland on slopes" and "buttongrass moorland on rises and broad valleys and flats" (di Folco 2007). All nutrients and the organic content are lower than figures given for organosols on Precambrian quartzite till. In particular the 2% organic content from the type locality is much lower than the 42–44% given by Bowman *et al.* (1986). This reflects the sandy composition of the surface substrate that had no visible peat. The pH of alkaline pans (on limestone) in the Hardwood Valley (southwest Tasmania) was generally above seven (Brown *et al.* 1982). Brown *et al.* (1982) found that plant species in and around alkaline pans responded individually to changes in pH and that strong boundaries were present at the edge of the pans with pH changes of more than three units over 20 cm. The sandy pans or washes observed in our study are strongly associated with a vegetation community that is distinct from the surrounding buttongrass moorland and reflects the similarly dramatic change from wet sand to acid organosols.

Vegetation

A list of vascular and non-vascular plant species observed at the Wallaby Bay and Swallow Creek *A. leucobryoides* sites is given in appendix 1. *A. leucobryoides* at Wallaby Bay and Swallow Creek is located in sparsely vegetated almost flat sandy washes or "sand pans". The Wallaby Bay washes with *A. leucobryoides* have greater species richness than the Swallow Creek washes but all have the following plants: *Leptocarpus tenax* (Labill.) R.Br., *Chordifex hookeri* (D.I.Morris) B.G.Briggs, *Actinotus suffocatus* (Hook.f.) Rodway, *Helichrysum pumilum* Hook.f., *Drosera binata* Labill., and/or *D. pygmaea* DC., and the mosses *Dicranoloma billardierei* (Broth.&Geh.) and/or *D. eucamptodontoides* (Broth.&Geh.). The vegetation at these sites fits the descriptions for both buttongrass moorland communities "daisy pans" and "mossy sand" (Jarman *et al.* 1988). Both communities are restricted to southwest Tasmania. Buttongrass moorland vegetation surrounding the sandy washes is a "standard blanket moor" community on peaty soil (Jarman *et al.* 1988) and is mapped as "sparse buttongrass moorland on slopes"-"MBR" (Harris & Kitchener 2005) on the Tasmanian Vegetation Map (TASVEG 1.3, Department of Primary Industries and Water). *A. leucobryoides* is most common in open areas of sand and is often associated with filamentous algae growing on the wet surface of the sand (Yamaguchi *et al.* 1990).

TABLE 1
Soil sample composition[1] (type locality, Wallaby Bay)

Exchangeable nitrogen (ppm)	Organic content (LOI) %	PH	Conductivity	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)
12	2	6.8	100	<1	12	100	50	40

[1] Determined by Allison Laboratories Pty Ltd, Hobart, Tasmania.

Total population estimate

At least 10 000 *A. leucobryoides* stems were observed across eight sandy washes during the one-day field survey at Wallaby Bay and Swallow Creek (table 2). The species occurs in localised patches in variable densities: a small number of counts found between 50–160 stems in 100 cm^2. The areas of the washes are variable with sizes of less than 10 m^2 being common. The occurrences north of Coffin Creek at Wallaby Bay contained the densest patches of the moss. The species rarely occurs across an entire sandy wash, more frequently occurring as variably sized patches within the wash. Further field survey is required to determine the extent of the species distribution, the area occupied within its range of occurrence and to gain a better estimation of the total population.

GENERAL DISCUSSION AND MANAGEMENT RECOMMENDATIONS

Conservation and reservation status

All known occurrences are in the Tasmanian Wilderness World Heritage Area. *A. leucobryoides* is currently listed as rare under the Tasmanian *Threatened Species Protection Act 1999*. It qualifies for listing as rare under state legislation as it is a species subject to stochastic risk of endangerment because of naturally small subpopulation sizes and naturally small area of occupancy (Tasmanian Threatened Species Scientific Advisory Committee 2001). Over-collecting was identified as a threat to the species (DPIW unpubl. data). The availability of *A. leucobryoides* axenic cultures from the University of London will help to alleviate some of the collecting pressure. Damage from field identification and monitoring is potentially a threat to the moss as removal of a layer of covering sand may be necessary for identification and this action can result in the breaking of stems, the apices of which sit at or just above the surface. It is possible that a loss of *A. leucobryoides* habitat from changed fire regimes and/or climate change may be an issue if the alluvial sands cease to accumulate, the bare sands dry out, or the pans are colonised by denser buttongrass moorland vegetation or scrub.

Further work recommended

This field survey provided the first extension of the known distribution of *A. leucobryoides* since it was originally found in 1987. Although more is now known of its habitat, future searches will still need to rely on ground truthing. While it is possible to observe open quartzite environments on aerial photographs, it is not possible to pick up the subtleties relating to microhabitat. This is particularly true for determining fine-grained sand, which appears to be an important feature of *A. leucobryoides* habitat, versus coarser gravel. It is likely that this species occurs in other fine-grained sandy quartzite washes between Birchs Inlet and Louisa Bay.

Targeted extension surveys of fine-grained sandy washes in southwest Tasmania would assist in determining the extent of occurrence, area of occupancy and providing a better estimate of total population size. This would provide information to reassess the conservation status of *A. leucobryoides*. The species is fragile and may be impacted upon during the simple act of wiping away sand to enable identification. In the long term a minimal intervention and visitation approach is recommended to minimise disturbance to this species.

It is recommended that monitoring be undertaken for habitat changes, such as the number, extent and size of sandy pans occupied by the species. This form of monitoring is likely to result in less damage to the species than monitoring the numbers of stems. A 60 m transect was established in March 2008, at the original Wallaby Bay site and is intended for long-term monitoring of the cover of the species in the pan.

ACKNOWLEDGEMENTS

A special thanks to Penny Tyson who went searching in sandy washes at Birchs Inlet and found a new site for the inconspicuous *Ambuchanania leucobryoides*; and Ian Houshold for geomorphic interpretation of sand collected from the type locality. Many thanks to Mikayla Jones (UTAS), Sib Corbett (DPIW), Lyn Cave (Tasmanian Herbarium), Rod Seppelt (Australian Antarctic Division; Honorary

TABLE 2
Total population summary for *Ambuchanania leucobryoides* in Tasmania

Site	Tenure	1:25 000 mapsheet	Year (first) last seen	Area occupied	Number of stems
1	Wallaby Bay TWWHA[1] (Southwest National Park)	Breaksea	(1987) 2008	observed in 5 pans south and 2 pans north of Coffin Creek – potential for more in this area >50m^2	10 000+
2	Swallow Creek TWWHA (Southwest National Park)	Louisa	(2008) 2008	observed in 1 pan – no potential for more in this area c. 10m^2	200+
3	Birchs Inlet TWWHA (Franklin-Gordon Wild Rivers National Park)	Birchs	(2008) 2008	observed in 2 pans – potential for more in this area	Unknown

[1] Tasmanian Wilderness World Heritage Area.

Botanist, Tasmanian Herbarium) and Alan Gray (Tasmanian Herbarium) for assisting with field searches; and Jean Jarman (Tasmanian Herbarium) for the provision of valuable field data. Thanks to Wendy Potts (DPIW) for comments on the manuscript.

REFERENCES

Bowman, D., Maclean, A. & Crowden, R. 1986: Vegetation-soil relations in the lowlands of south-west Tasmania. *Australian Journal of Ecology* **11**: 141–153.

Brown, M.J., Crowden, R.K. & Jarman, S.J. 1982: Vegetation of an alkaline pan – acidic peat mosaic in the Hardwood River Valley, Tasmania. *Australian Journal of Ecology* **7**: 3–12.

Buchanan, A. 2007: *A Census of the Vascular Plants of Tasmania & Index to the Student's Flora of Tasmania*, Tasmanian Herbarium, www.tmag.tas.gov.au/Herbarium/Herbarium2.htm. (accessed May 2008).

Bureau of Meteorology 2008: Tasmanian climate averages. www.bom.gov.au/weather/tas. (accessed May 2008).

Crum, H. & Seppelt, R.D. 1999: *Sphagnum leucobryoides* reconsidered. *Contributions from the University of Michigan Herbariun* **22**: 29–31

Dalton, P.J., Seppelt, R.D. & Buchanan, A.M. 1991: An annotated checklist of Tasmanian mosses. *In* Banks, M.R., Smith, S.J., Orchard, A.E. & Kantvilas, G. (eds): Aspects of Tasmanian botany – A tribute to Winifred Curtis. *Papers and Proceedings of the Royal Society of Tasmania,* Hobart: 15–32.

di Folco, M.B. 2007: Tasmanian Organic Soils. Unpublished PhD thesis, University of Tasmania.

Harris, S. & Kitchener, A. 2005: *From Forest to Fjaeldmark. Descriptions of Tasmania's Vegetation.* Department of Primary Industries, Water and Environment. Printing Authority of Tasmania, Hobart: 432 pp.

Jarman, S.J., Kantvilas, G. & Brown, M.J. 1988: *Buttongrass Moorland in Tasmania.* Research Report No. 2. Tasmanian Forest Research Council Inc., Hobart: vii, 158 pp.

McCarthy, P.M. 2003: *Catalogue of Australian Liverworts and Hornworts.* Flora of Australia Supplementary Series No. 21; Australian Biological Resources Study, Canberra.

Moore, P.D. & Bellamy D.J. 1974: *Peatlands.* London: Elek Science: vi, 221 pp.

Seppelt, R.D. 2000: The Sphagnopsida (Sphagnaceae; Ambuchananiaceae) in Australia. *Hikobia* **13**: 163–183.

Shaw, A.J. 2000: Phylogeny of the Sphagnopsida based on chloroplast and nuclear DNA sequences. *Bryologist* **103**: 277–306.

Shaw, A.J., Cox, C.J. & Boles, S.B. 2003: Polarity of peatmoss *(Sphagnum)* evolution: who says bryophytes have no roots? *American Journal of Botany.* **90**(12): 1777–787.

Streimann, H. & Klazenga, N. 2002: *Catalogue of Australian Mosses.* Australian Biological Resources Study, Canberra. Volume 17: 259 pp.

Tasmanian Threatened Species Scientific Advisory Committee 2001: *Guidelines Used for the Listing of Species under the Tasmanian Threatened Species Protection Act 1995.* Department of Primary Industries, Water and Environment, Hobart: 4 pp.

Yamaguchi, T., Seppelt, R.D., Iwatsuki, Z. & Buchanan, A.M. 1990: *Sphagnum* (sect. *Buchanania) leucobryoides* sect. et sp. nov. from Tasmania. *Journal of Bryology.* **16**: 45–54.

(accepted 7 October 2008)

APPENDIX 1
Plant species occurring at *Ambuchanania leucobryoides* sites

Species Name	Wallaby Bay (from 7 sandy washes)	Swallow Creek (from 1 sandy wash)
Non-Vascular		
Ambuchanania leucobryoides (T. Yamag., Seppelt. & Z.Iwat.) Seppelt & H.A. Crum	+	+
Dicranoloma billarderi (Brid. ex anon.) Par.	+	
Dicranoloma eucamptodontoides (Broth. & Geh.) Par.	+	+
Goebelobryum unguiculatum (Hook.f. et Taylor) Grolle	+	
Vascular		
Shrubs		
Bauera rubioides Andrews	+	
Baeckea leptocaulis Hook.f.	+	
Cenarrhenes nitida Labill.	+	
Epacris obtusifolia Sm.	+	
Leptospermum nitidum Hook.f.	+	
Melaleuca squamea Labill.	+	
Sprengelia propinqua A.Cunn. ex DC.	+	
Herbs		
Actinotus suffocatus (Hook.f.) Rodway	+	
Drosera binata Labill.	+	+
Drosera pygmaea DC.	+	
Drosera arcturi Hook.	+	+
Helichrysum pumilum var. *pumilum* Hook.f.	+	
Utricularia dichotoma Labill.		+
Utricularia lateriflora R.Br.	+	
Oschatzia saxifraga (Hook.f.) Walp.	+	
Graminoids		
Baumea tetragona (Labill.) S.T.Blake	+	
Calorophus erostris (C.B.Clarke) L.A.S.Johnson & B.G. Briggs	+	+
Centrolepis monogyna (R.Br.) B.G.Briggs	+	+
Chordifex hookeri (D.I.Morris) B.G.Briggs	+	+
Empodisma minus (Hook.f.) L.A.S.Johnson & D.F.Cutler	+	+
Eurychorda complanata (R.Br.) B.G.Briggs & L.A.S. Johnson	+	
Gaimardia amblyphylla W.M.Curtis	+	
Gymnoschoenus sphaerocephalus (R.Br.) Hook.f.	+	+
Haemodorum distichophyllum Hook.	+	
Lepidosperma filiforme Labill.	+	
Leptocarpus tenax (Labill) R.Br.	+	+
Schoenus lepidosperma subsp. *filiforme* (F.Muell.) K.L.Wilson	+	
Schoenus lepidosperma subsp. *lepidosperma*		+
Sporadanthus tasmanicus (Hook.f.) B.G.Briggs & L.A.S.Johnson	+	
Tetraria capillaris (F.Muell.) J.M.Black	+	+
Xyris marginata Rendle	+	
Xyris sp.	+	
Ferns and fern allies		
Gleichenia dicarpa R.Br.	+	+
Selaginella uliginosa (Labill.) Spring	+	

A PRELIMINARY CENSUS OF THE MACROFUNGI OF MT WELLINGTON, TASMANIA – THE SEQUESTRATE SPECIES

by James M. Trappe, Neale L. Bougher, Michael A. Castellano, Andrew W. Claridge, Genevieve M. Gates, Teresa Lebel and David A. Ratkowsky

(with one table and one appendix)

Trappe, J.M., Bougher, N.L., Castellano, M.A., Claridge, A.W., Gates, G.M., Lebel, T. & Ratkowsky, D.A. 2008: A preliminary census of the macrofungi of Mt Wellington, Tasmania – the sequestrate species. *Papers and Proceedings of the Royal Society of Tasmania* 142(1): 85–96. ISSN 0080–4703. Department of Forest Ecosystems and Society, Oregon State University, Corvallis, Oregon 97331–5752, USA (JMT); Department of Environment and Conservation, Western Australian Herbarium, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983, Australia (NLB); US Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331, USA (MAC); Department of Environment and Climate Change, Parks and Wildlife Group, Southern Branch, PO Box 2115, Queanbeyan, New South Wales 2620, Australia and School of Physical, Environmental and Mathematical Sciences, University of New South Wales, Australian Defence Force Academy, Northcott Drive, Canberra, Australian Capital Territory 2600, Australia (AWC); School of Plant Science, University of Tasmania, Private Bag 55, Hobart, Tasmania 7001, Australia (GMG); Royal Botanic Gardens Melbourne, Birdwood Avenue, South Yarra, Victoria 3141, Australia (TL); School of Agricultural Science, University of Tasmania, Private Bag 54, Hobart, Tasmania 7001, Australia (DAR*). *Author for correspondence.

This is the fourth and final contribution in a series of papers providing a preliminary documentation of the macrofungi of Mt Wellington, Tasmania. The earlier papers dealt with the gilled Basidiomycota, the non-gilled Basidiomycota and the Ascomycota, respectively, excluding the sequestrate species. The present paper completes the series by dealing with the sequestrate species, of which seven Ascomycota, 76 Basidiomycota, three Glomeromycota and one Zygomycota were found. Seven new genera and 25 new species, to be formally described elsewhere, are recorded.

Key Words: hypogeous, Ascomycota, Basidiomycota, Glomeromycota, Zygomycota, earthballs, truffles, truffle-like fungi.

INTRODUCTION

Earlier papers in this preliminary census of the Mt Wellington macrofungi concerned the gilled fungi (Ratkowsky & Gates 2002), the non-gilled Basidiomycota (Gates & Ratkowsky 2004) and the Ascomycota (Gates & Ratkowsky 2005), but in each case the sequestrate species (commonly referred to as "earthballs" if Basidiomycota and "truffles" if Ascomycota) were ignored. This paper completes the series by dealing with the validly published sequestrate species that have been found and identified on Mt Wellington. Also included are some new genera and new species (shown in bold type in appendix 1) that are being described elsewhere. Nomenclature of the previously described species generally follows the two published volumes of the catalogue and bibliography of Australian fungi (May & Wood 1997, May *et al.* 2003), with several exceptions.

The history of the earliest collections and study of sequestrate fungi in Australia has been detailed by Lebel & Castellano (1999). In Tasmania, R.C. Gunn included fungi amongst his numerous botanical collections made between 1832 and 1850 and sent to the Royal Botanic Gardens, Kew. The Reverend M.J. Berkeley's contribution to the *Flora Tasmaniae* (Berkeley 1859) included species described from material sent by Gunn. The next major collector of Tasmanian fungi was the seemingly indefatigable L. Rodway, who, despite his training and official position in dentistry, became the (honorary) Government Botanist from 1892–1932, and included fungi amongst his numerous collections of plant groups from vascular plants to bryophytes. Unlike R.C. Gunn, who passed specimens on to a herbarium in the United Kingdom without describing or studying them, Rodway actively collaborated by correspondence with others, such as the Victoria-based plant pathologist D. McAlpine, the Kew-based G. Massee, the American mycologist C.G. Lloyd, and the South Australia-based J.B. Cleland. This active collaboration resulted in some joint publications (e.g., McAlpine & Rodway 1896, Massee & Rodway 1898), but Rodway frequently published alone (e.g., Rodway 1898, 1912, 1918, 1920, 1921, 1924a, b, 1925a, b, 1926, 1929).

MATERIALS AND METHODS

Surveys for sequestrate species on Mt Wellington were carried out by the present authors and their co-workers at different times and in different groupings of collectors. For details of the survey zones used by G.M. Gates and D.A. Ratkowsky collecting jointly, see Ratkowsky & Gates (2002), which includes a map of the survey area. The fieldwork is part of a continuing programme of surveys of macrofungi throughout Tasmania. During the period April 1998–August 2005, over 300 visits to Mount Wellington were made. Joint forays in various combinations of J.M. Trappe, M. Amaranthus, N.L. Bougher, M.A. Castellano, W. Colgan III, T. Lebel, N. Malajczuk and R. Robinson focused on sequestrate fungi on 2 and 7 May 1990, 17–18 May 1991, and 15 July 1993. In each of these forays the participants fortuitously encountered good diversity and large numbers of fungi.

Trappe and Castellano have examined all of L. Rodway's sequestrate fungus type collections from Mt Wellington as housed either at The Tasmanian Herbarium (HO) or the Royal Botanic Gardens, Kew, U.K. (K). Our descriptions of Rodway's species are based on his holotypes and expanded to reflect additional information from the new collections found

in the forays noted above. Types of the new taxa found in our collections will be deposited at HO as they are published. Isotypes and other collections will be deposited in various other Australian herbaria, e.g., The Royal Botanic Gardens of Victoria (MEL), the Australian National Herbarium (CANB), and the Western Australian Herbarium (PERTH). Splits from collections with abundant specimens will also be deposited at K and the Mycological Herbarium of Oregon State University, USA (OSC). Representative material of previously described species is held in the private herbaria of the various authors, awaiting deposition in HO and other Australian herbaria.

Genera and species are listed alphabetically within each of the orders to which they were assigned by Hibbett & Binder (2006), Hosaka *et al.* (2006), Matheny *et al.* (2006), Miller *et al.* (2006) and Redecker & Raab (2006) or as amended by recent work on the Australian sequestrate fungi. Nomenclature at the genus level in the Russulales follows that of Lebel & Trappe (2000), Lebel & Castellano (2002) and Lebel & Tonkin (2007), and at the species level Lebel (2003a, b) and Lebel & Tonkin (2007). For the cortinarioid sequestrate fungi, nomenclature at both genus and species level generally follows Francis & Bougher (2002). Published photographs or drawings of species, where available, are cited after each description in appendix 1.

New taxa or new combinations not published by the time this paper is in press are cited by italicised and boldfaced letters of the alphabet, e.g., ***New genus A, new species A,*** etc. New genera appear at the end of the list for each order. Species that are to be transferred to another genus are listed under their present names but with comment on the intended new generic disposition.

RESULTS

Two orders of the sequestrate Ascomycota have been found on Mt Wellington: Elaphomycetales, with one genus and one species, and Pezizales, with five genera and six species. Gates & Ratkowsky (2005) recorded 10 genera and 15 species of non-sequestrate Pezizales, more than twice as many as the sequestrate species.

The Mt Wellington sequestrate Basidiomycota are represented by six orders: Agaricales, with 12 genera and 29 species; Atheliales, with one genus and two species; Boletales, with six genera and seven species; Gomphales, with one genus and two species; Hysterangiales, with seven genera and 15 species; and Russulales, with six genera and 21 species for totals of 33 genera and 76 species. Thus, the sequestrate Basidiomycota of Mt Wellington contains five times more genera and nearly 11 times more species than the sequestrate Ascomycota.

The Glomeromycota are represented by two orders: Diversisporales, with one genus and one species, and Glomerales, with one genus and two species. The Zygomycota has only the order Endogonales with one genus and one species.

In all, seven new genera and 25 new species are represented in the Mt Wellington collections of sequestrate fungi.

DISCUSSION

Extensive collecting in southeastern mainland Australia has revealed a generally low proportion of sequestrate Ascomycetes to sequestrate Basidiomycota (Trappe, Claridge, Lebel & Castellano unpubl. data). This trend also applies to Mt Wellington.

The epigeous, nonsequestrate, ectomycorrhizal genera of the Basidiomycota listed for Mt Wellington by Ratkowsky & Gates (2002) and Gates & Ratkowsky (2004) include *Amanita, Cortinarius, Dermocybe* and *Descolea* in the Agaricales; *Boletellus, Boletus, Paxillus* and *Scleroderma* in the Boletales; *Ramaria* in the Gomphales; and *Lactarius* and *Russula* in the Russulales, in all containing 36 species. The 74 hypogeous, sequestrate species listed in appendix 1 for the sequestrate relatives of these orders plus the Hysterangiales (not represented by any epigeous, nonsequestrate species) thus total more than twice as many species as the ectomycorrhizal, epigeous, nonsequestrate genera. Diversification of hypogeous species related to their epigeous ancestors at Mt Wellington is particularly striking for the epigeous Cortinariaceae and Russulaceae (table 1). This probably reflects the evolutionary climatic selection pressure of warm, dry weather and recurring drought so often common during the mushroom fruiting season in Australia (Trappe & Claridge 2005), which in turn may account for the estimate that Australia has produced about one-third of the world's hypogeous, sequestrate fungal species (Mueller *et al.* 2006). A large number of undescribed *Cortinarius* species not included in the survey results of Ratkowsky & Gates (2002) and Gates & Ratkowsky (2004) occurs on Mt Wellington (Gates & Ratkowsky unpubl. data). Given the relatively short collecting time devoted to hypogeous

TABLE 1
Numbers of epigeous, nonsequestrate, ectomycorrhizal species of *Cortinarius, Descolea, Lactarius* and *Russula* reported by Ratkowsky & Gates (2002) and Gates & Ratkowsky (2004) and their related, hypogeous, sequestrate species of the order Agaricales at Mt Wellington

Epigeous taxa		Hypogeous taxa	
Genus	Number of species	Genera related to epigeous genera	Number of species
Cortinarius	13	*Dermocybe, Protoglossum, Quadrispora, Thaxterogaster, Timgrovea,* new genus A	17
Descolea	2	*Descomyces*	5
Lactarius	3	*Arcangeliella, Gastrolactarius*	7
Russula	5	*Cystangium, Gymnomyces, Russula*	13
Total	23	Total	42

fungi there, numerous additional hypogeous taxa probably remain to be discovered. The ratio of epigeous to hypogeous species will change as more collecting takes place, but the important result is the splendid diversity of both groups of macrofungi offered by Mt Wellington.

The nomenclature of sequestrate fungi, in common with that of epigeous fungi, has been fluid as evidence of phylogenetic relationships is continually uncovered. The fluidity of taxonomic concepts may be illustrated by an examination and discussion of a monograph (Cunningham 1944) devoted to the Australasian (defined as Australia and New Zealand) Gasteromycetes, considered at that time to be a subclass of the class Basidiomycetes. Of the five orders in that subclass, the one composed of anastomosing, persistent tramal plates lined with the hymenium, viz. the Hymenogastrales, which no longer exists, will be considered here. Part of the Hymenogastrales is now placed in the Agaricales, part in the Boletales, part in the Gomphales, part in the Hysterangiales and part in the Russulales (Matheny *et al.* 2006, Hibbett & Binder 2006, Hosaka *et al.* 2006, Miller *et al.* 2006). In the treatment of Cunningham (1944), two genera are conspicuous by their scope, each of which includes some very disparate species. One of these, *Hymenogaster* Vittad., contained spores ranging from being perfectly smooth to having a rugulose-areolate, verrucose, or strongly reticulated exospore. Although these sequestrate species are statismosporic, thereby preventing a spore print from being obtained, the spore colour as seen through a light microscope would show a gradation from hyaline to dark brown to purplish brown. The taxonomic position of most of the species considered to belong to *Hymenogaster* in Cunningham's treatment has been clarified by molecular phylogenetic analyses (Peintner *et al.* 2001, Matheny *et al.* 2006).

The species formerly placed in *Hymenogaster* we now variously assign to *Descomyces* Bougher & Castellano, *Hymenogaster* Vittad., *Protoglossum* Massee, *Thaxterogaster* Singer, *Timgrovea* Bougher & Castellano, and two new, undescribed genera (Genus A and B). *Thaxterogaster* and *Protoglossum* are considered by Peintner *et al.* (2002) to be synonyms of the mushroom genus *Cortinarius.* That decision, however, was based solely on an ITS phylogeny of a few more than 100 species of *Cortinarius* and related genera, including sequestrate forms. Many of the branches were poorly resolved; multigene analyses are now considered important for reliable phylogenies, and in some cases RNA polymerase II genes have proven more useful in delineating species of *Cortinarius* than ITS (Frøslev *et al.* 2005). *Cortinarius* is estimated to contain as many as 2000 species worldwide (Kirk *et al.* 2001), but more than 4000 species names have been published for the genus (Frøslev *et al.* 2005). *Cortinarius* is poorly known in Australia; estimates of the total number of species and their phylogenetic relationships are presently impossible. Moreover, the genes involved in evolution of epigeous to sequestrate morphologies are unknown, so their influence on molecular phylogenetic placement of species is speculative. We regard subsuming all species of *Thaxterogaster* and other sequestrate members of the Cortinariaceae into the huge and poorly resolved genus *Cortinarius* as premature. Accordingly, for purposes of this paper we use the sequestrate generic names.

An analogous circumstance applies to certain stipitate but sequestrate, hypogeous relatives of *Russula,* being placed by some authors in *Russula,* by others in *Macowanites.* The two sequestrate *'Macowanites'* species found at Mt Wellington have both been described and named as *Russula* spp.: we list them as they were published rather than make new combinations that might prove premature.

The second genus of the Hymenogastrales *sensu* Cunningham (1944) that has unacceptably disparate elements is *Octaviania* Vittad. As was the case with Cunningham's treatment of *Hymenogaster,* the range of spore colour and type of ornamentation is very large. Some of the species listed there are now considered better placed in *Arcangeliella* Cavara, *Cystangium* Singer & A.H. Sm., *Gastrolactarius* J.M. Vidal, *Gymnomyces* Massee & Rodway, *Horakiella* Castellano & Trappe, *Hydnangium* Wallr. or *Stephanospora* Pat. Had Melzer's reagent been employed in Cunningham's day for studies of sequestrate species, the amyloid reaction obtained for *Arcangeliella, Cystangium, Gastrolactarius* and *Gymnomyces* spores would have readily separated them from the others, none of which is amyloid.

Recent molecular phylogenetic studies of an array of sequestrate genera formerly placed variously in the Boletales, Gomphales, Hymenogastrales, Phallales and Lycoperdales has revealed that greatly disparate macro- and micromorphologies cluster together in the new order Hysterangiales (Hosaka *et al.* 2006). Thus *Austrogautieria* with ridged spores and a firm gleba, *Hysterangium* with smooth to minutely warty spores enclosed in a persistent utricle and a cartilaginous gleba, and the Australian endemic *Mesophellia* with smooth spores enclosed in an ephemeral utricle and a powdery spore mass in its gleba all fall into the Hysterangiales clade.

ACKNOWLEDGEMENTS

Trappe's participation in this study was supported in part by CSIRO Sustainable Ecosystems. Lebel and Trappe received support from Australian Biological Resources Study grants 95130 and 20650, Trappe and Castellano from U.S. National Science Foundation Grant BSR 9201421, and Trappe and Claridge from an Australian Biological Resources Study contract on a monograph of the hypogeous members of the Sclerodermatineae of Australia. M. Amaranthus, W. Colgan III, N. Malajczuk, R. Robinson and J. States generously contributed their Mt Wellington collections for our use. We are especially grateful to the personnel of HO and K for giving us access to Rodway's types, and to those herbaria as well as CANB, MEL, OSC and PERTH for accessioning our own collections.

REFERENCES

Beaton, G., Pegler, D.N. & Young, T.W.K. 1984a: Gasteroid Basidiomycota of Victoria State, Australia: I. Hydnangiaceae. *Kew Bulletin of Miscellaneous Information* **39**: 499–508.

Beaton, G., Pegler, D.N. & Young, T.W.K. 1984b: Gasteroid Basidiomycota of Victoria State, Australia: II. Russulales. *Kew Bulletin of Miscellaneous Information* **39**: 669–698.

Beaton, G., Pegler, D.N. & Young, T.W.K. 1985a: Gasteroid Basidiomycota of Victoria State, Australia: III. Cortinariales. *Kew Bulletin of Miscellaneous Information* **40**: 167–204.

Beaton, G., Pegler, D.N. & Young, T.W.K. 1985b: Gasteroid Basidiomycota of Victoria State, Australia: IV. *Hysterangium. Kew Bulletin of Miscellaneous Information* **40**: 435–444.

Beaton, G., Pegler, D.N. & Young, T.W.K. 1985c: Gasteroid Basidiomycota of Victoria State, Australia: V–VII. Boletales, Agaricales and Stephanosporaceae. *Kew Bulletin*

of Miscellaneous Information **40**: 573–598.

Beaton, G., Pegler, D.N. & Young, T.W.K. 1985d: Gasteroid Basidiomycota of Victoria State, Australia: VIII-IX. Additional taxa. *Kew Bulletin of Miscellaneous Information* **40**: 827–840.

Beaton, G. & Weste, G. 1977: The genus *Labyrinthomyces. Transactions of the British Mycological Society* **69**: 243–247.

Beaton, G. & Weste, G. 1978: The genus *Sphaerozone. Transactions of the British Mycological Society* **71**: 164–167.

Beaton, G. & Weste, G. 1982a: A new species of *Scleroderma* from Victoria, Australia. *Transactions of the British Mycological Society* **79**: 41–43.

Beaton, G. & Weste, G. 1982b: Australian hypogaean Ascomycetes. *Transactions of the British Mycological Society* **79**: 455–468.

Beaton, G. & Weste, G. 1983: The genus *Mesophellia* in Victoria, Australia. *Transactions of the British Mycological Society* **80**: 209–218.

Beaton, G. & Weste, G. 1984: Victorian hypogaean Gasteromycetes: Mesophelliaceae. *Transactions of the British Mycological Society* **82**: 665–671.

Berch, S.M. & Fortin, A. 1983: Lectotypification of *Glomus macrocarpum* and proposal of new combinations: *Glomus australe, Glomus versiforme,* and *Glomus tenebrosum* (Endogonaceae). *Canadian Journal of Botany* **61**: 2608–2617.

Berkeley, M.J. 1859: Fungi. *In* J.D. Hooker: *The Botany of the Antarctic Voyage of H.M. Discovery Ships Erebus and Terror in the Years 1839–1843. Part III. Flora Tasmaniae. Vol. 2. Monocotyledones and Acotyledones.* Lovell Reeve, London: 241–282.

Boedijn, K.B. 1939: The Tuberales of the Netherlands Indies. *Bulletin du Jardin Botanique de Buitenzorg Série III* **16**: 236–244.

Bougher, N.L. & Castellano, M.A. 1993: Delimitation of *Hymenogaster sensu stricto* and four new segregate genera. *Mycologia* **85**: 273–293.

Bougher, N.L. & Lebel, T. 2002: Australasian sequestrate (truffle-like) fungi. XII. *Amarrendia* gen. nov.: an astipitate, sequestrate relative of *Torrendia* and *Amanita* (Amanitaceae) from Australia. *Australian Systematic Botany* **15**: 513–525.

Bougher, N.L. & Malajczuk, N. 1986: An undescribed species of hypogeous *Cortinarius* associated with *Eucalyptus* in Western Australia. *Transactions of the British Mycological Society* **86**: 301–304.

Bougher, N.L. & Syme, K. 1998: *Fungi of Southern Australia.* University of Western Australia Press, Nedlands, W.A.: 391 pp.

Bucholtz, F. 1912: Beiträge zur Kenntnis der Gattung *Endogone* Link. *Beihefte zum Botanischen Centralblatt, Abt.* 2, **29**: 147–224.

Claridge, A.W. & May, T.W. 1994: Mycophagy among Australian mammals. *Australian Journal of Ecology* **19**: 251–275.

Claridge, A.W. & Trappe, J. M. 2004: Managing habitat for mycophagous (fungus-feeding) mammals: a burning issue? *In* Lunney, D. (ed.): *Conservation of Australia's Forest Fauna, 2nd Edition.* Royal Society of New South Wales, Sydney: 936–946.

Claridge, A.W., Trappe, J.M. & Castellano, M.A. 2001: Australasian truffle-like fungi. X. *Gymnopaxillus* (Basidiomycota, Austropaxillaceae). *Australian Systematic Botany* **14**: 273–281.

Cribb, J.W. 1958: The Gasteromycetes of Queensland – V. *Octaviania* and *Hydnangium. University of Queensland Department of Botany Papers* **3**: 247–254.

Cunningham, G.H. 1932: The Gasteromycetes of Australasia, XV. The genera *Mesophellia* and *Castoreum. Proceedings of the Linnean Society of New South Wales* **57**: 313–322.

Cunningham, G.H. 1934: The Gasteromycetes of Australasia, XVI. Hymenogastraceae, Part I: the genera *Rhizopogon, Melanogaster* and *Hymenogaster. Proceedings of the Linnean Society of New South Wales* **59**: 156–172.

Cunningham, G.H. 1938: The Gasteromycetes of Australasia, XVIII. *Transactions of the Royal Society of New Zealand* **67**: 408–410.

Cunningham, G.H. 1944: *The Gasteromycetes of Australia and New Zealand.* John McIndoe, Dunedin, New Zealand (reprinted 1979, J. Cramer, Vaduz, Liechtenstein).

Dodge, C.W. & Zeller, S.M. 1934: *Hymenogaster* and related genera. *Annals of the Missouri Botanical Garden* **21**: 625–708.

Fischer, E. 1908: Zur Morphologie der Hypogaeen. *Botanische Zeitung* **66**: 141–168.

Francis, A.A. & Bougher, N.L. 2002 [2003]: Historical and current perspectives in the systematics of Australian cortinarioid sequestrate (truffle-like) fungi. *Australasian Mycologist* **21**: 81–93.

Frøslev, T.G., Matheny, P.B. & Hibbett, D.S. 2005: Lower level relationships in the mushroom genus *Cortinarius* (Basidiomycota, Agaricales): a comparison of RPB1, RPB2 and ITS phylogenies. *Molecular Phylogenetics and Evolution* **37**: 602–618.

Gates, G.M. & Ratkowsky, D.A. 2004: A preliminary census of the macrofungi of Mt Wellington, Tasmania – the non-gilled Basidiomycota. *Papers and Proceedings of the Royal Society of Tasmania* **138**: 53–59.

Gates, G.M. & Ratkowsky, D.A. 2005: A preliminary census of the macrofungi of Mount Wellington, Tasmania – the Ascomycota. *Papers and Proceedings of the Royal Society of Tasmania* **139**: 49–52.

Gilkey, H.M. 1954: Taxonomic notes on Tuberales. *Mycologia* **45**: 783–793.

Giachini, A.J., Oliveira, V.L., Castellano, M.A. & Trappe, J.M. 2000: Ectomycorrhizal fungi in *Eucalyptus* and *Pinus* plantations in southern Brazil. *Mycologia* **92**: 1166–1177.

Grgurinovic, C.A. 1997: *Larger Fungi of South Australia.* The Botanic Gardens of Adelaide and State Herbarium and the Flora and Fauna of South Australia Handbooks Committee, Adelaide: 725pp.

Hibbett, D.S. & Binder, M. 2006: Molecular systematics and biological diversification of Boletales. *Mycologia* **98**: 971–981.

Hosaka, K., Bates, S.T., Beever, R.E., Castellano, M.A., Colgan III, W., Domínguez, L., Geml, J., Giachini, A.J., Kenney, S.R., Nouhra, E.R., Simpson, N.B., Spatafora, J.W. & Trappe, J.M. 2006: Molecular phylogenetics of the gomphoid-phalloid fungi with an establishment of the new subclass Phallomycetidae and two new orders. *Mycologia* **98**: 949–959.

Kirk, P.M., Cannon, P.F., David, J.C. & Stalpers, J.A. 2001: *Ainsworth and Bisby's Dictionary of the Fungi,* 9th Edition. CAB International, Wallingford, UK: 655 pp.

Lebel, T. 2003a: Australian sequestrate (truffle-like) fungi. XIII. *Cystangium* (Russulales, Basidiomycota). *Australian Systematic Botany* **16**: 371–400.

Lebel, T. 2003b: Australian sequestrate (truffle-like) fungi. XIV. *Gymnomyces* (Russulales, Basidiomycota). *Australian Systematic Botany* **16**: 401–426.

Lebel, T. & Castellano, M.A. 1999: Australasian truffle-like fungi. IX. History and current trends in the study of the taxonomy of sequestrate macrofungi from Australia and New Zealand. *Australian Systematic Botany* **12**: 803–817.

Lebel, T. & Castellano, M.A. 2002: Type studies of sequestrate Russulales. II. Australian and New Zealand species related to *Russula. Mycologia* **94**: 327–354.

Lebel, T. & Tonkin, J.E. 2007: Australasian species of *Macowanites* are sequestrate species of *Russula* (Russulaceae, Basidiomycota). *Australian Systematic Botany* **20**: 355–381.

Lebel, T. & Trappe, J.M. 2000: Type studies of sequestrate Russulales. I. Generic type species. *Mycologia* **92**: 1188–1205.

Lloyd, C.G. 1922: Mycological Notes 67. *Mycological Writings* **7**: 1137–1168.

Massee, G. & Rodway, L. 1898: New hypogeous fungi from Tasmania. *Kew Bulletin of Miscellaneous Information* **138**: 124–128.

Matheny, P.B., Curtis, J.M., Hofstetter, V., Aime, M.C., Moncalvo, J.-M., Ge, Z.-W., Yang, Z.-L., Slot, J.C., Ammirati, J.F., Baroni, T.J., Bougher, N.L., Hughes, K.W., Lodge, D.J., Kerrigan, R.W., Seidl, M.T., Aanen, D.K., DeNitis, M., Daniele, G.M., Desjardin, D.E., Kropp, B.R., Norvell, L.L., Parker, A., Vellinga, E.C., Vilgalys, R. & Hibbett, D.S. 2006: Major clades of Agaricales: a multilocus phylogenetic overview. *Mycologia* **98**: 982–995.

May, T.W. & Wood, A.E. 1997: *Catalogue and Bibliography of Australian Macrofungi* 1. Basidiomycota p.p. (Fungi of Australia, Volume 2A). Australian Biological Resources Study, Canberra: 348 pp.

May, T.W., Milne, J., Shingles, S. & Jones, R.H. 2003: *Catalogue and Bibliography of Australian Fungi* 2. Basidiomycota p.p. & Myxomycota p.p. (Fungi of Australia, Volume 2B). Australian Biological Resources Study, Canberra: 452 pp.

McAlpine, D. & Rodway, L. 1896: Australian fungi. *Agricultural Gazette of New South Wales* **7**: 84–87.

McGee, P.A. & Trappe, J.M. 2002: The Australian zygomycetous mycorrhizal fungi. II. Further Australian sporocarpic Glomaceae. *Australian Systematic Botany* **15**: 115–124.

Miller, S.L., Larsson, E., Larsson, K.-H., Verbeken, A. and Nuytinck, J. 2006: Perspectives in the new Russulales. *Mycologia* **98**: 960–970.

Mueller, G.M., Schmit, J.P., Leacock, P.R., Buyck, B., Cifuentes, J., Desjardin, D.E., Halling, R.E., Hjortstam, K., Iturriaga, T., Larsson, K.-H., Lodge, D.J., May, T.W., Minter, D., Rajchenberg, M., Redhead, S.A., Ryvarden, L., Trappe, J.M., Watling, R. & Wu, Q. 2006: Global diversity and distribution of macrofungi. *Biodiversity and Conservation* **16**: 37–48.

Pegler, D.N. & Young, T.W.K. 1979: The gasteroid Russulales. *Transactions of the British Mycological Society* **72**: 353–388.

Peintner, U., Bougher, N.L., Castellano, M.A., Moncalvo, J.-M., Moser, M. M., Trappe, J. M. & Vilgalys, R. 2001: Multiple origins of sequestrate fungi related to *Cortinarius* (Cortinariaceae). *American Journal of Botany* **88**: 2168–2179.

Peintner, U., Moser, M. & Vilgalys, R. 2002: *Thaxterogaster* is a taxonomic synonym of *Cortinarius*: new combinations and new names. *Mycotaxon* **81**: 177–184.

Ratkowsky, D.A. & Gates, G.M. 2002: A preliminary census of the macrofungi of Mount Wellington, Tasmania – the Agaricales. *Papers and Proceedings of the Royal Society of Tasmania* **136**: 89–100.

Redecker, D. & Raab, P. 2006: Phylogeny of the Glomeromycota (arbuscular mycorrhizal fungi): recent developments and new gene markers. *Mycologia* **98**: 885–895.

Redecker, D., Raab, P., Oehl, F., Camacho, F.J. & Courtecuisse, R. 2007: A novel clade of sporocarp-forming species of glomeromycotan fungi in the *Diversisporales* lineage. *Mycological Progress* **6**: 35–44.

Rodway, L. 1898: Underground fungi of Tasmania. *Reports of the Meeting of the Australasian Association for the Advancement of Science* **7**: 488–493.

Rodway, L. 1912: The Hymenogastraceae of Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **1911**: 21–31.

Rodway, L. 1918: Botanical notes. *Papers and Proceedings of the Royal Society of Tasmania* **1917**: 105–110.

Rodway, L. 1920: Notes and additions to the fungus flora of Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **1919**: 110–116.

Rodway, L. 1921: Additions to the fungus flora of Tasmania, Part 3. *Papers and Proceedings of the Royal Society of Tasmania* **1920**: 153–159.

Rodway, L. 1924a: Description of two underground fungi. *Papers and Proceedings of the Royal Society of Tasmania* **1923**: 108.

Rodway, L. 1924b: Tasmanian Hymenogastraceae. *Papers and Proceedings of the Royal Society of Tasmania* **1923**: 151–161.

Rodway, L. 1925a: Two interesting fungi. *Papers and Proceedings of the Royal Society of Tasmania* **1924**: 8.

Rodway, L. 1925b: Tasmanian Discomycetes. *Papers and Proceedings of the Royal Society of Tasmania* **1924**: 90–122.

Rodway, L. 1926: Notes on some rare and interesting cryptogams. *Papers and Proceedings of the Royal Society of Tasmania* **1925**: 167–170.

Rodway, L. 1929: Note on *Gautieria* in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **1928**: 72.

Singer, R. & Smith, A.H. 1960: Studies on secotiaceous fungi IX. The asterogastraceous series. *Memoirs of the Torrey Botanical Club* **21**: 1–112.

Stewart, E.L. & Trappe, J.M. 1985: The new genus *Austrogautieria* (Basidiomycotina), segregate from *Gautieria*. *Mycologia* **77**: 674–687.

Thaxter, R. 1922: A revision of the Endogoneae. *Proceedings of the American Academy of Arts and Sciences* **57**: 291–351.

Trappe, J.M. 1975: The genus *Amylascus* (Tuberales). *Transactions of the British Mycological Society* **65**: 496–499.

Trappe, J.M. 1979: The orders, families, and genera of hypogeous Ascomycotina (truffles and their relatives). *Mycotaxon* **9**: 297–340.

Trappe, J.M., Castellano, M.A. & Malajczuk, N. 1992: Australasian truffle-like fungi. II. *Labyrinthomyces, Dingleya* and *Reddellomyces* gen. nov. (Ascomycotina). *Australian Systematic Botany* **5**: 597–611.

Trappe, J.M., Castellano, M.A. & Malajczuk, N. 1996: Australasian truffle-like fungi. VII. *Mesophellia* (Basidiomycotina, Mesophelliaceae). *Australian Systematic Botany* **9**: 773–802.

Trappe, J.M. & Claridge, A.W. 2003: Australasian sequestrate (truffle-like) fungi. 15. New species from tree line in the Australian Alps. *Australasian Mycologist* **22**: 27–38.

Trappe, J.M. & Claridge, A.W. 2005: Hypogeous fungi: evolution of reproductive and dispersal strategies through interactions with animals and mycorrhizal plants. *In* Dighton, J., White, J.F. & Oudemans, P. (eds): *The Fungal Community – Its Organization and Role in the Ecosystem*. Taylor & Francis, Boca Raton, Florida: 613–623.

Trappe, J.M. & Claridge, A.W. 2006: Australasian sequestrate (truffle-like) fungi. 17. *Hydnoplicata convoluta*, the 'bounced about' Australian truffle (Ascomycota, Pezizaceae). *Australasian Mycologist* **25**: 33–35.

Tulasne, L.-R. & Tulasne, C. 1851: Fungi Hypogaei. Friedrich Klincksieck, Paris (reprinted 1970, A. Asher & Co., Vaals, The Netherlands).

White, N.H. 1956: A note on truffle fungi in Australia with special reference to *Labyrinthomyces steenisii* Boedijn. *Transactions of the British Mycological Society* **39**: 341–342.

Zeller, S.M. & Dodge, C.W. 1929: *Hysterangium* in North America. *Annals of the Missouri Botanical Garden* **16**: 83–123.

Zhang, B.-C. & Minter, D.W. 1988: Two new species of *Labyrinthomyces* from New Zealand, with notes on taxonomy of the genus. *Systema Ascomycetum* **7**: 45–55.

Zhang, B.-C. & Minter, D.W. 1989: *Gymnohydnotrya:* a new hypogeous ascomycete genus from Australia. *Mycological Research* **92**: 192–198.

(accepted 4 November 2008)

APPENDIX 1

Species descriptions of Mt Wellington sequestrate fungi

ASCOMYCOTA

[Elaphomycetales]

Elaphomyces ***new species A*** — Fruit bodies 8–25 mm broad, subglobose, enclosed in golden brown, yellowish brown to orange brown mycelium with intermixed soil, debris and mycorrhizae. Peridium tough, firm, with an outer layer of pyramidical warts <0.5 mm tall, a middle layer forming a more or less uniformly dark line directly beneath the outer layer, and an inner layer grey to pale violet brown, rosy brown or brown. Gleba hollow in youth, soon filling with cottony ascogenous hyphae, at maturity filled with a black, powdery spore mass. Spores globose, (22–) 24–28 (–32) µm broad, including the ornamentation of coarse, flattened amorphous warts 4–5 µm tall.

[Pezizales]

Amylascus tasmanicus (Rodway) Trappe — Up to 3 cm broad, chestnut brown, ridged and furrowed, minutely verrucose and tomentose, with a basal, hyphal attachment. Gleba of convoluted folds of tissue, penetrated with meandering veins and labyrinthine chambers up to 2 mm broad. Asci weakly but evenly blue in iodine solution. Spores globose, 20–26 µm broad including the ornamentation of hyaline rods and cones 1 (–2) µm tall and 0.5–1.5 µm broad. Illustrations — Trappe (1975: plate 56).

Dingleya phymatodea (B.C. Zhang & Minter) Trappe, Castellano & Malajczuk — Fruit bodies up to 2.5 cm broad, subglobose, brown, with irregularly polygonal warts up to 1 mm broad and 0.4 mm tall. Gleba yellowish brown at maturity, with chambers lined with a hymenium of paraphyses, asci and spores. Spores globose, pale yellow, 17–22 (–25) µm broad excluding the ornamentation of crowded, rounded warts 1–5 µm broad. Illustrations — Zhang & Minter (1988: 53, 55); Trappe *et al.* (1992: 602).

Dingleya tectiascus Trappe, Castellano & Malajczuk — Fruit bodies small, subglobose, pale brown, with irregular, flattened warts up to 0.8 mm broad. Gleba solid, brown with labyrinthine chambers lined with a hymenium. Spores globose, 18–12 µm broad excluding the ornamentation of crowded, hyaline warts up to 4 µm broad. Differs from other species in the genus because the paraphyses exceed the asci to form a tightly interwoven epithelium that covers the ascus tips. Illustrations — Trappe *et al.* (1992: 600).

Gymnohydnotrya echinulata (G.W. Beaton) B.C. Zhang & Minter — Fruit bodies white to greyish olive, up to 2 cm broad, convoluted, with one to several chambers, the cylindrical asci in a hymenium covering the sporocarp surface but not lining the chambers. Spores 17–23 x 12–16 µm excluding the ornamentation of irregular spines up to 4.5 x 2 µm joined in places by an arch-like reticulum. Illustrations — Beaton & Weste (1978: 165), as *Sphaerozone echinulatum*; Zhang & Minter (1989: 194).

Hydnoplicata convoluta (McAlpine) Trappe & Claridge — Among the more widely distributed sequestrate species in temperate Australian forests, its much convoluted and infolded, glabrous, white to pale greyish yellow fruit bodies are 1–4 cm broad. In youth they may have a single chamber with a small opening, but as they mature they fold inwardly so much as to form a series of large, open, labyrinthine chambers. Asci turn blue in iodine solution. Illustrations — McAlpine & Rodway (1896: figs 11–14), as *Hydnocystis convoluta*; Gilkey (1954: 786), as *Hydnoplicata whitei*; Beaton & Weste (1982b:. 457) and Bougher & Syme (1998: 103), both *Peziza whitei*; Trappe & Claridge (2006: 34).

Labyrinthomyces varius (Rodway) Trappe — Fruit bodies almost perfectly globose, about the same colour as dark soil and often with much soil clinging to their tomentose surfaces. Cut in half, the firm gleba at maturity presents an attractive pattern of brown, broad, labyrinthine chambers separated by broad veins of white, sterile tissue. Asci borne in a hymenium that lines the chambers and are more than twice as long as the paraphyses. Spores globose, up to 25 µm broad, ornamented with broad, rounded warts. Illustrations — Boedijn (1939: 239), White (1956: plate 11) and Beaton & Weste (1977: 244), all as *Labyrinthomyces steenisii*; Trappe (1979: 309); Trappe *et al.* (1992: 600).

BASIDIOMYCOTA

[Agaricales]

Amarrendia lignicolor (G.W. Beaton, Pegler & T.W.K. Young) Bougher & T. Lebel — Fruit bodies up to 1.5 cm broad, pale brown to ivory, in age with some reddish stains. Gleba chambered, pale pinkish brown to greyish orange. Spores smooth, 6–8 x 4.5–6 (6.5) µm, hyaline. Illustrations — Beaton *et al.* (1985c: 579, 585) as *Alpova lignicolor*; Bougher & Lebel (2002: 521).

Dermocybe globuliformis (Bougher) Bougher & Trappe — Although not strictly sequestrate, this diminutive species is completely hypogeous. Pileus rarely exceeds 2 cm broad and is bright yellow, as are the veil, stipe, and immature lamellae. Stipe reduced to less than 7 mm long, never lifting the pileus out of the soil. As spores mature, they colour the lamellae bright cinnamon and are discharged onto the persistent, submembranous veil. Illustrations — Bougher & Malajczuk (1986: 302, 303) and Bougher & Syme (1998: 250, 251), both as *Cortinarius globuliformis*.

Descomyces albellus (Massee & Rodway) Bougher & Castellano — The white, felty peridium of this small, ubiquitous fungus has a patchy to abundant overlay of veil-like yellow tufts and fibrils, under which is a pellis of interwoven to appressed hyphae with scattered, sphaerocyst-like cells. Gleba white in youth, dark brown by maturity. It abounds in many forest types, including disturbed habitats, and has been introduced around the world as a hitchhiker on roots of introduced eucalypt seedlings. Illustrations — Cunningham (1934: 169 and 1944: plate xxxiii), as *Hymenogaster albellus*; Bougher & Castellano (1993: 278, 281).

Descomyces albus (Klotzsch) Bougher & Castellano — Differentiated from *D. albellus* by having a pellis of inflated cells so abundant as to form an epithelium. Otherwise, the two are indistinguishable and have often been confused by past workers. Both are similarly abundant and widely distributed. Illustrations — Beaton *et al.* (1985a: 191, 202–203), as *Hymenogaster albus*; Bougher & Syme (1998: 268, 269).

Descomyces giachinii Trappe, V. L. Oliveira, Castellano & Claridge — Species of *Descomyces* fairly much all look alike macroscopically. This species differs from the others in its combination of a lack of an epithelium of large, rounded cells and the presence of citriform spores 14–20 (–23) x (8–) 9–11 (–13.5) µm ornamented with a small-meshed reticulum up to 1 µm tall. Illustrations — Giachini *et al.* (2000: 1172).

Descomyces ***new species A*** — Macroscopically similar to other *Descomyces* species, it differs from *D. giachinii* in having an ornamentation of warts, lines and a coarse, partial, meandering to alveolate reticulum 1–1.5 (–3) µm tall.

Hydnangium carneum Wallr. — The pink peridium and gleba are distinctive. A columella may be lacking, poorly developed, or occasionally conspicuous, but an easily detachable, white, basal pad is nearly always present. Spores globose to subglobose, hyaline, 12–18 x 11–17 µm excluding the ornamentation of conical spines. One of the more common and widespread eucalypt mycorrhizal fungi, it has been introduced around the world where eucalypt seedlings have been transported from Australia. Illustrations — Beaton *et al.* (1984a: 501, 503); Cunningham (1944: plate xxxiii); Grgurinovic (1997: 295); Bougher & Syme (1998: 197).

Hydnangium ***new species A*** — Differs from *H. carneum* by its much smaller, globose spores, 6–10 µm broad. The fruit bodies are up to 22 mm broad, with a white to pink or brownish pink peridium. The pink to pinkish brown gleba may or may not have a prominent basal pad, but no columella has been observed so far. Glebal chambers can be up to 5 x 1.5 mm, the longest radiating from the basal attachment or pad.

Hymenogaster maidenii Rodway — This species will be transferred to *Descomyces*. It macroscopically resembles other *Descomyces* species but differs microscopically in lacking an epithelium and having spores 13–16 x 9–11 µm excluding the ornamentation of a partial to complete, finely labyrinthine reticulum 0.2–0.6 µm tall.

Hymenogaster nanus Massee & Rodway — This species needs transfer to *Protoglossum*. Fruit bodies up to 3 cm broad, greyish brown, with a thick, gelatinous pellicle. Gleba brown, with a usually well developed sterile base. Spores brown and mostly ellipsoid, (13–) 15–16 x 8–9.5 µm excluding the ornamentation of warts ± 1 µm tall. Illustrations — Cunningham (1944: plate xxxiii).

Hysterogaster fusisporus (Massee & Rodway) G.W. Beaton, Pegler & T.W.K. Young. — Fruit bodies up to 2 cm broad, white to yellowish white, felty. Gleba ivory in youth, becoming brown by maturity. Spores smooth, dextrinoid, and fusoid, 15–22 x 7–8 µm. Illustrations — Dodge & Zeller (1934: plate 18), and Cunningham (1944: plate xxxiii), both as *Hymenogaster fusisporus*; Beaton *et al.* (1985c: 589, 593).

Hysterogaster tasmanicus (G.H. Cunn.) G.W. Beaton, Pegler & T.W.K. Young — Fruit bodies dirty white, smooth, up to 12 mm broad. Gleba brownish yellow with a basal projection. Spores broadly fusoid, moderately dextrinoid, 11–13 x 6.5–9 µm, shorter and broader than those of *H. fusisporus*. Illustrations — Cunningham (1934: 169 and 1944: plate xxxiii), as *Hymenogaster tasmanicus*; Beaton *et al.* (1985c: 589, 593).

Protoglossum niphophilum Trappe & Claridge — Peridium gelatinous-viscid and white with a violet to lilaceous tinge or violet to lilac overall, up to 800 µm thick. Gleba loculate and at maturity rusty brown from massed spores. Odour slightly of radish. Spores 12–15 (–16) x 6–8 (–9) µm excluding the ornamentation of uncrowded minute warts and ridges. Illustrations — Trappe & Claridge (2003: 30, 31).

Protoglossum violaceum (Massee & Rodway) T.W. May — Fruit bodies up to 3 cm broad, the peridium with a thick, gelatinous, bright greyish violet pellicle. Gleba cinnamon, loculate with a small to prominent, white sterile base but little or no columella. Spores broadly ellipsoid to obovoid, 8.5–10 (–11) x 6–7 µm excluding the ornamentation of fine warts. Illustrations — Cunningham (1944: plate xxxiii), as *Gymnoglossum violaceum*; Beaton *et al.* (1985a: 187, 201), as *Hymenogaster violaceus*.

Protoglossum viscidum (Massee & Rodway) T.W. May — Fruit bodies subglobose to slightly turbinate. Peridium thick, gelatinous-viscid, brownish orange to orange brown. The brown gleba has relatively large chambers. This species has been subject to considerable confusion in the past, having been synonymised with *P. luteum* by various workers. The ellipsoid spores of *P. viscidum*, however, are 14–18 x 9–12 µm, substantially larger than those of the globose-spored *P. luteum*. Except for the illustration cited below, other past illustrations purported to be *P. viscidum* are *P. luteum*. Illustrations — Bougher & Castellano (1993: 278), as *Cortinomyces viscidus*.

Protoglossum ***new species A*** — Fruit bodies orange brown to dark reddish brown, smooth, with a thick, glutinous-warty pellicle and musty odour. Gleba deep cinnamon, loculate, with an inconspicuous to prominent, white, basal pad. Spores brownish yellow, ellipsoid, 10–14 (–16) x 7–9 µm excluding the ornamentation of amorphous, ill defined warts and ridges 0.5–1 µm tall.

Protoglossum ***new species B*** — Fruit bodies canary yellow, smooth, with a thick, gelatinous pellicle. Gleba deep cinnamon, with a basal pad sometimes elongated into a short columella. Spores brown, ellipsoid to broadly ellipsoid, 10–15 x 7.5–10 µm, ornamented with crowded warts ± 0.2 µm long and broad.

Protoglossum ***new species C*** — Fruit bodies up to 2.5 cm broad, lilac, with a thick, gelatinous pellicle. Gleba loculate, cinnamon from the spore mass, the trama with hyphae up to 20 or more µm broad; basal pad absent or inconspicuous, columella lacking. Spores light cinnamon, 10–12 x 5.5–6 (–7) µm excluding the ornamentation of fine warts and ridges ± 0.5 µm tall. It differs from *P. violaceum* by its broad tramal hyphae and spores with a larger length:width ratio.

Protoglossum ***new species D*** — Peridium orange brown to reddish brown as dried, with a thick, gelatinous pellicle. Gleba dark cinnamon with an inconspicuous, yellowish basal pad. Spores pale brownish yellow, ellipsoid, 11–14 x 7–9 µm excluding the hyaline ornamentation of minute warts and wrinkles 0.2–0.5 (–1) µm tall.

Quadrispora oblongispora (G. Beaton, Pegler & T.W.K. Young) Bougher & Castellano — Peridium gelatinous-viscid, thick, dull yellow to orange yellow. At maturity the dark brown gleba has chambers up to 1.5 mm broad. This genus differs from *Protoglossum* by having spores that cling together in tetrads after discharge from the basidia. Illustrations — Beaton *et al.* (1985a: 187, 202), as *Hymenogaster oblongisporus*; Bougher & Castellano (1993: 286).

Thaxterogaster ***new species A*** — Fruit bodies up to 11 x 18 mm, in youth totally enclosed in a thick, white veil that breaks up on the upper surface of specimens as they expand to expose a pale, brownish grey peridium. The cinnamon gleba has chambers that radiate from the contorted stipe, which is truncate or percurrent as a columella; the thick, peronate veil persists on the stipe and attaches to the margin of the peridium. The odour is faintly of chlorine.

Thaxterogaster ***new species B*** — Up to 16 x 13 mm, this species is subconic to globose with a light yellowish brown peridium supporting silvery patches of veil. It features a robust, percurrent stipe-columella 4–5 mm broad and a marginate base 8–12 mm broad; the margin of the gleba is pressed against the upper side of the basal stipe bulb and attached to or slightly seceded from it by a thick, fibrillose veil. The spores are minutely punctate.

Thaxterogaster ***new species C*** — Up to 16 x 18 mm, this species has a silky-shining, violet peridium, the margin of which is confluent

with the stipe. The chambered gleba has a cylindric stipe-columella up to 3 mm broad with yellowish white to violet flesh. The brownish spores are ellipsoid, 8–10 x 6–8 µm, excluding the ornamentation of warts 0.2–0.5 µm tall and broad.

Timgrovea reticulata (G.H. Cunn.) Bougher & Castellano — The small fruit bodies are dirty white mottled with brown and yellow patches. The gleba is rust brown at maturity, its chambers are up to 1 mm broad, and it has a small, pale basal pad but no columella. The spores are ornamented with reticulum ridges up to 2 µm tall and 1–2 µm broad. Illustrations — Cunningham (1944: plate xxxiii), as *Hymenogaster reticulatus*; Bougher & Castellano (1993: 289).

New genus A new species A — Attractive rich violet, felty-smooth, dry, fruit bodies up to 2.5 cm broad. Gleba chambered, a rich coffee colour with a violet basal pad or short columella, or the last two structures often lacking. Spores ellipsoid, 7.5–10 x 6–7 µm excluding the ornamentation of warts 0.1–1 µm tall.

New genus A new species B — Fruit bodies small, ellipsoid, dirty white, dry, the thick peridium enclosing a dark cinnamon gleba. Spores ellipsoid to obovoid, 11–15 x 8–10 µm, dark reddish brown, ornamented with irregular warts and longitudinally aligned ridges up to 1 µm tall, 3 µm broad and 6 µm long.

New genus A *levisporus* — This new combination will be based on *Hymenogaster levisporus* Massee & Rodway. The small, young, silvery white fruit bodies stand out brightly when raked from the soil but become brownish white towards full maturity. Fruit bodies up to 3 cm broad with a chambered, cinnamon coloured gleba typically with a conical, white to brownish white basal pad that varies greatly from barely noticeable to prominent, sometimes occupying half or more of the gleba or narrowing to a percurrent columella. Spores brown with warts so minute as to be easily overlooked at magnifications of less than x1000. Illustrations — Cunningham (1944: plate xxxiii) and Dodge & Zeller (1934: plate 18), both as *Hymenogaster levisporus*; Beaton *et al.* (1985a: 170, 199), as *Thaxterogaster levisporus*.

New genus B *aureus* — This new combination will be based on *Hymenogaster aureus* Rodway. Fruit bodies up to 2 cm broad, bright yellow, fading to pale yellow by full maturity. Gleba white in youth, becoming pinkish brown at maturity. Spores smooth, fusoid or irregular, 9–19 x 5–8 µm, similar to spores of *Hysterogaster* but not dextrinoid. Illustrations — Cunningham (1944: plate xxxiii) and Beaton *et al.* (1985a: 183), both as *Hymenogaster aureus*.

New genus C *ochraceum* — Based on *Secotium ochraceum* Rodway, this collection seems not to fit in any known genus, but Rodway's specimen is not in good enough condition to be well described or serve as a type collection. It may belong in the Bolbitiaceae, close to *Setchelliogaster*.

[Atheliales]

Stephanospora flava (Rodway) G.W. Beaton, Pegler & T.W.K. Young — Small, bright yellow, often lumpy and irregular, its gleba is dull greyish olive to greyish brown. The hyaline, ellipsoid to subglobose spores are 10–12 µm broad excluding the ornamentation of crests and spines and a crown-like collar around the sterigmal attachment. Related to the poroid genus *Lindtneria*, it occurs in wet forests and is one of the few sequestrate species of rain forests. Illustrations — Cunningham (1944: plate xxxiii) and Cribb (1958: 253), both as *Octaviania flava*; Singer & Smith (1960: 107), as *Octavianina flava*; Beaton *et al.* (1985c: 595, 596); Claridge & May (1994: 255).

Stephanospora ***new species A*** — Resembles *S. flava* but with larger, more globose spores 10–15 µm broad excluding the ornamentation of tapering spines and wedges 1–4 µm tall and a distinct basal collar encircling the sterigmal attachment; the spores cling together in fours.

[Boletales]

Gymnopaxillus vestitus Claridge, Trappe & Castellano — Up to 2 cm broad, irregular and lumpy, sometimes confluent in rows. The white, cottony peridium is often patchy. The chambered, bright rust to cinnamon coloured gleba has an irregular, columnar to dendroid columella, but that may be lacking in some specimens. Spores are smooth, ellipsoid to narrowly ellipsoid, vivid golden yellow. Illustrations — Claridge *et al.* (2001: 277).

Hydnangium clelandii Rodway — This species will be transferred to the genus *Horakiella*. Up to 2 cm broad, tomentose in patches, dingy yellow, in cross section reddening where cut. Gleba firm with locules packed with a dark brown spore mass at maturity. Spores pale brown, globose to subglobose, ellipsoid, obovoid or subangular, 25–30 (–40) x 30–35 (–40) µm, with 2 wall layers, the surface wrinkled or with an obscure reticulum ± 0.1 µm tall. Illustrations — Cunningham (1944: plate xxxiii), as *Octaviania clelandii*.

Octaviania ***new species A*** — Rarely more than one cm broad, the fruit bodies are dirty white in youth but later darken to yellowish olive or olive, with brown to black or sometimes blue stains. The labyrinthiform glebal chambers filled with a gelatinous suspension of cinnamon brown, globose spores ornamented with cones and spines 2–3 µm tall.

Scleroderma paradoxum G.W. Beaton — The completely hypogeous fruit bodies are 6–25 mm broad, subglobose to flattened or irregular, initially sordid cream colour to sordid yellow but at maturity dark brown. The gleba is black and firm at early maturity but becomes a powdery spore mass at maturity. The odour is faint in youth, becoming musty, fishy or like cat urine by maturity. Illustrations — Beaton & Weste (1982a: 42, 43).

New genus D — This new genus will be based on *Chamonixia vittatispora* G.W. Beaton, Pegler & T.W.K. Young. Peridium initially white with some blue tinges, at senescence becoming greyish orange. The brown gleba has a small, whitish basal pad. Spores pale brown at maturity, smooth, bilaterally symmetrical, in transverse section subangular with 5 or 6 longitudinal facets. It is a species complex that needs a new genus. Illustrations — Beaton *et al.* (1985c: 583, 585).

New genus E new species A — The small fruit bodies are brownish white with a pale gleba containing smooth, colourless, ellipsoid to narrowly ellipsoid spores 6–8 x 3–4 µm with a length:width ratio of 1.6–2.7.

New genus E new species B — Differs from *new genus E new species A* by its ellipsoid to broadly ellipsoid spores with a length:width ratio of 1.4–1.8.

[Gomphales]

Gautieria albida (Massee & Rodway) G.H. Cunn. sensu Zeller & C.W. Dodge — Fruit bodies with a white peridium, a prominent basal rhizomorph, and a loculate, orange yellow gleba with a dendroid columella. Spores mostly ellipsoid, 17–26 x 13–17 µm, including the ornamentation of 10–12, frequently forking, longitudinal, humped ridges 1–5 µm tall and 2–4.5 µm broad. Cunningham's (1944) and Beaton's *et al.* (1985a) descriptions and illustrations for

G. albida are actually that of an undetermined, probably undescribed *Austrogautieria* species.

Gautieria ***new species A*** — Fruit bodies with a continuous to patchy, yellowish white to pale yellow, fibrillose peridium. The brown gleba has a grey, cartilaginous basal pad that may lack a columella or extend as an inconspicuous one. Spores mostly ellipsoid, (12–) 18–23 x 12–6 µm, excluding the ornamentation of 7–10, rounded, longitudinal ridges up to 5 µm tall that greatly exceed the spore apex but do not converge there.

[Hysterangiales]

Austrogautieria chlorospora E.L. Stewart & Trappe — The small fruit bodies are brown to light dull reddish brown. The gleba is soft and strikingly yellowish green to dark green from the massed, yellowish green spores ornamented with 8–13 hyaline, longitudinal, sinuate, forking, acute-margined ridges up to 2.5 µm tall. Originally thought to be related to *Gautieria* in the Gomphales, *Austrogautieria* has since been found by molecular phylogenetic techniques to belong to the Hysterangiales (Hosaka *et al.* 2006). Illustrations — Stewart & Trappe (1985: 678).

Austrogautieria clelandii E.L. Stewart & Trappe — Small and smooth, with a readily separable, brownish white peridium up to 1 mm thick, this species has a rubbery, moderate brown to dark brown gleba with a narrow, translucent, dendroid columella. Spores 16–21 x 12–17 µm excluding the ornamentation of 8–11 longitudinal, smooth, acute-margined ridges up to 3 µm tall and 1–2.5 µm broad. The peridium has a prominent layer of pseudoparenchyma. Illustrations — Cunningham (1944: plate xxxiv), as *Gautieria clelandii*; Stewart & Trappe (1985: 682).

Austrogautieria costata E.L. Stewart & Trappe — Macroscopically, this species resembles *A. clelandii.* However, its spores are smaller (12–16 x 9–12 µm excluding the ornamentation of 8–12 longitudinal ridges up to 3 µm tall and 1–2.5 µm broad) than those of the latter, and its peridium is of interwoven hyphae rather than of inflated cells. Illustrations — Cunningham (1944: plate xxxiv) and Beaton *et al.* (1985a: 197, 203), both as *Gautieria costata;* Stewart & Trappe (1985: 680); .

Austrogautieria ***new species A*** — This species resembles *A. clelandii.* However, its spore ornamentation differs strikingly from *A. clelandii,* being irregular, longitudinal patches and ridges 1–1.5 µm tall and 2–3 µm broad, with roughened and channelled edges and a crested, irregular, obtuse to subangular margin. Many spores produce germ tubes in the fruit bodies.

Austrogautieria ***new species B*** — Fruit bodies up to 3 x 5 cm, with a brown peridium and gleba, lacking a columella. Spores fusoid to narrowly citriform with a cupped sterigmal appendage and a distinctive apical, cylindric, obtuse prolongation 2–4 x 2 µm. The spores are ornamented with 6–9 longitudinal, forking ridges 1–3 µm tall and with acute margins.

Castoreum radicatum Cooke & Massee — Fruit bodies with a stout, root-like basal rhizomorph, the peridium smooth and elastic when fresh, hard when dry, brown, 2–2.5 mm thick, 3-layered: outer layer up to 400 µm thick; middle layer up to 750 µm thick, of loosely interwoven hyphae and mycorrhizae; inner layer up to 2 mm thick, of highly refractive hyphae. Gleba a greyish orange, powdery spore mass with interspersed capillitial hyphae. Illustrations — Cunningham (1944: plate xxxv); Beaton & Weste (1984: 668), Grgurinovic (1997: 605).

Chondrogaster ***new species A*** — Fruit bodies small, subglobose to globose, enclosed in a sheath of white mycelium and mycorrhizae. Gleba dark yellowish olive. The spores are smooth, hyaline, ellipsoid, 13–14 x 4–5 µm, with a patchy, irregular utricle and a remnant of the sterigma attached at the base.

Chondrogaster ***new species B*** — Fruit bodies small, enclosed in a mix of whitish to pinkish mycelium and mycorrhizae. The gleba is pale olive. The hyaline spores are broadly ellipsoid to broadly fusoid, 10–12 x 5–6 µm, and enclosed in a lumpy, coarse, appressed utricle. The squat, broad spores with their coarse utricle differentiate this species from *new species A.*

Hysterangium affine Massee & Rodway — Fruit bodies up to 2 cm broad with one or more stout, basal rhizomorphs. The smooth, white peridium stains rose where bruised and readily separates from the green, cartilaginous gleba. *H. affine* has been variously interpreted in the past, but the type collection has ellipsoid to oblong spores 11–13 x 3.5–5 µm enclosed in an irregularly inflated utricle and a peridium of hyaline, polyhedral cells 50–75 x 30–40 µm. Illustrations — Rodway (1912: plate III, fig. 9); Zeller & Dodge (1929: plates 2–3); Cunningham (1944: plate xxxiv); Beaton *et al.* (1985b: 439, 441).

Hysterangium gardneri E. Fischer — The tomentose to felty, white to pale brown peridium has much adherent soil and organic debris, stains pink where bruised or cut, and does not separate readily from the cartilaginous, green to dark green gleba. Gleba with a narrow, dendroid, translucent columella. Rhizomorphs are adpressed overall and the same colour as the peridium. The species was originally described from California, where it was collected under introduced eucalypts. Illustrations — Fischer (1908: plate 6, fig. 19).

Hysterangium inflatum Rodway — Up to 2.5 cm broad, the fruit bodies have a mostly tomentose, dull white peridium that stains pale brown to pale reddish brown when exposed. Gleba at maturity dark olive to nearly black with a dendroid, narrow, translucent columella. The narrowly ellipsoid spores are enclosed in a utricle laterally inflated up to 2.5 µm. Illustrations — Cunningham (1944: plate xxxiv); Beaton *et al.* (1985b: 437, 441).

Hysterangium ***new species A*** — Up to 16 mm broad and subglobose to lobed or irregular, the smooth fruit bodies are white and stain pink to red where bruised. The readily separable peridium is up to 1 mm thick. Gleba dark greyish green, cartilaginous, with a dendroid columella. The smooth spores are 11–13 x 5–6 µm and their lack of a utricle is unusual for this genus.

Mesophellia glauca (Cooke & Massee) D. A. Reid — The dirt encrusted spheres, often fused together in 2's and 3's, resemble globose soil clods and a have a 3-layered peridium: a thin, brittle outer layer, a thick, white, soft, middle layer that incorporates masses of mycorrhizal rootlets, and a thin, leathery or rubbery inner layer. The centre consists of a core of rubbery tissue attached to the inner peridial layer by minute to robust columns, in between which is a powdery, greyish olive mass of spores. Animals remove the peridium and most of the spores to get at the inner core, which they eagerly eat. The spores are thus dispersed by air movement, by dusting the fur, whiskers and paws of the animals, or by being accidentally ingested with the core. Illustrations — Beaton & Weste (1983: 210, 211, 213); Claridge & May (1994: 258); Trappe *et al.* (1996: 786, 790); Grgurinovic (1997: 602); Claridge & Trappe (2004: 937).

Nothocastoreum cretaceum (Lloyd) G. W. Beaton — Small, orange-brown and subglobose to ellipsoid, this species has a thin, brittle

peridium that ruptures at the top in an irregular stellate pattern to expose the grey, powdery spore mass. Many fruit bodies often cluster just under the soil surface. When animals such as wallabies scratch them out to eat, the spore powder is released to the air. Illustrations — Lloyd (1922: fig. 1978), as *Diploderma cretaceum*; Cunningham (1932: plate xi and 1944: plates xvii, xxxv), as *Castoreum cretaceum*; Beaton & Weste (1984: 667); Grgurinovic (1997: 605).

New genus F *neglectum* — This new genus will be based on *Hysterangium neglectum* Massee & Rodway. The subglobose to flattened fruit bodies are white with brown stains and fibrillose. Peridium separable, up to 1 mm thick. The dark brown, gelatinous gleba has a grey, translucent, dendroid columella. The smooth, thick-walled spores are 14–19 (–21) µm with an amorphous but distinct utricle and are agglutinated together in bunches. Illustrations — Cunningham (1944: plate xxxiv), as *Hysterangium neglectum.*

[Russulales]

Arcangeliella australiensis (Berk. & Broome) C. W. Dodge — One of several species in the "smooth, orange species complex" of small, Australian species with whey-like to milky latex, it differs from the others by its globose to subglobose spores 6–7 (–9) µm broad, ornamented with a fine, amyloid reticulum 0.2–0.5 µm tall and a pileipellis of appressed to emergent hyphae with only occasional inflated cells and rare dermatocystidia. The gleba is pale orange-yellow to pale orange. It has been misinterpreted by past workers such as Beaton *et al.* (1984b); our examination of the holotype showed it to be an earlier name for *Zelleromyces corkii* Trappe & Claridge. Illustrations — Trappe & Claridge (2003: 30, 31), as *Zelleromyces corkii.*

Arcangeliella claridgei (Trappe) Trappe & Claridge — Another member of the "smooth, orange species complex", *A. claridgei* differs from the others by its globose to subglobose spores 6–9 µm broad ornamented with amyloid ridges 0.2–1 µm tall in a zebroid pattern and its pileipellis an epithelium of inflated cells. Illustrations — Trappe & Claridge (2003: 30, 31), as *Zelleromyces claridgei.*

Arcangeliella daucina (G.W. Beaton, Pegler & T.W.K. Young) J.M. Vidal — Another member of the smooth, orange species complex that differs from the others by its globose spores 8–10.5 µm broad ornamented with a coarse, strongly amyloid, complete reticulum up to 2.5 µm tall and a dark orange to brownish orange peridium with an epithelium of inflated cells 10–20 µm broad. Illustrations — Beaton *et al.* (1984b: 685) and Bougher & Syme (1998: 136, 137), both as *Zelleromyces daucinus.*

Arcangeliella ***new species A*** — Still another member of the smooth, orange species complex, differing from the others by its globose to subglobose spores 6–7 (–8) µm broad excluding the ornamentation of a fine reticulum 0.2–1.5 µm tall and a moderate orange peridium with an epithelium of inflated cells 5–15 µm broad.

Arcangeliella ***new species B*** — Finally, another member of the smooth, orange species complex, differing from the others by its globose spores 7–9(–10) µm broad ornamented with amyloid ridges ± 0.5 µm tall in a zebroid pattern and its brownish orange to orange brown pileipellis of interwoven hyphae surmounted by a tangled turf of hyphal tips.

Cystangium flavovirens T. Lebel — The olive-yellow peridium, ivory to yellow, loculate gleba and often robust stipe are distinctive. The peridium is an epithelium up to 110 µm thick, composed of 5–8 tiers of rounded cells 6–11 µm broad overlain by a patchy layer of upright hyphal tips that become repent with age. The ellipsoid to subglobose spores are 8–9.5 x 7.5–8.5 µm excluding the ornamentation of amyloid warts often joined in groups of 2–7 by irregular ridges <0.5 µm tall. Illustrations — Lebel (2003a: 378, 379).

Cystangium megasporum (Rodway) T. Lebel & Castellano — Peridium smooth to irregularly roughened or pubescent, whitish to pale cream colour, sometimes becoming brown with age. Gleba cream colour, with small, irregular locules. Columella and stipe missing. Spores globose, ornamented with coarse, crowded spines so strongly amyloid that they render the spore nearly opaque. Illustrations — Cunningham (1944: plate xxxiii), as *Octaviania megaspora*; Lebel & Castellano (2002: 336, 337).

Cystangium rodwayi (Massee) A.H. Sm. — Fruit bodies up to 3 cm broad, whitish, pruinose to finely tomentose. Gleba with a well defined, white, usually curved stipe-columella 2–3 mm broad. The spores are globose, 7–10 µm broad excluding the ornamentation of low warts connected to form short, branched, irregular ridges in a partial reticulum. Illustrations — Cunningham (1944: plate xxxiv), as *Secotium rodwayi*; Lebel and Castellano (2002: 350).

Cystangium seminudum (Massee & Rodway) T. Lebel & Castellano — Fruit bodies small, white to cream colour or brownish, subglobose, pubescent overall or in patches, soft to firm. Gleba white, sometimes with brown patches, columella rudimentary or absent. The hymenium contains very large cystidia, which extend well beyond the basidia. The globose spores are ornamented with strongly amyloid spines. Illustrations — Cunningham (1944: plate xxxiii), as *Octaviania seminuda*; Pegler & Young (1979: 376) and Beaton *et al.* (1984b: 679), both as *Gymnomyces seminudus*; Lebel & Castellano (2002: 339, 340, 341).

Cystangium sessile (Massee & Rodway) Singer & A.H. Smith — Fruit bodies 2–4 cm broad, white, sometimes staining slightly pink when exposed, glabrous, with a white, usually percurrent stipe-columella. Gleba sublamellate to chambered, often exposed around the stipe. The hymenium contains abundant, very large cystidia. Spores subglobose, ornamented with irregularly amyloid spines and cones. Illustrations — Cunningham (1944: plates ix, xxxiv), as *Secotium sessile*; Pegler & Young (1979:366); Beaton *et al.* (1984b: 673, 694); Lebel & Trappe (2000: 1192).

Cystangium sparsum T. Lebel — Fruit bodies up to 2 cm broad, smooth or rugose at base, sordid white, becoming pale yellow mottled with brown. Gleba cream colour to pale tan, chambered. Stipe and columella absent or the latter represented as a basal pad or narrow, percurrent strand. Odour faintly of chlorine. Spores globose to subglobose, ornamented with sparse, amyloid warts isolated or clustered, <0.5 µm tall. Illustrations — Lebel (2003a: 389, 390).

Gastrolactarius ***new species A*** — This species resembles those of the "smooth, orange species complex" of *Arcangeliella* as seen from above, but unlike those it clearly has a straight to recurved stipe up to 5 mm long when viewed from below. The stipe emerges from a gelatinous, percurrent, orange columella. The brownish orange peridium has a patchy to continuous epithelium of rounded cells surmounted by a suprapellis of cystidia and tangled hyphae. Spores globose to subglobose, 7–10 µm broad excluding the ornamentation of a reticulum 0.5–1.5 µm tall.

Gymnomyces eburneus T. Lebel — This globose to subglobose species has a usually smooth, very white peridium that sometimes stains slightly brown when bruised. Gleba initially white, later becoming cream colour to pale yellow. Columella usually absent, but sometimes a narrow strand develops from the basal pad to the sporocarp apex. Odour faintly of radish at maturity. Illustrations — Lebel (2003b: 410, 411).

Gymnomyces glarea T. Lebel — *Glarea* is Latin for gravel: the fruit bodies resemble pebbles. Up to 22 mm broad, the fruit bodies have a smooth, white peridium that soon becomes brownish mottled with brown stains. Gleba initially ivory, soon developing brown stains. A stipe may be lacking or present but inconspicuous. The spores are globose to subglobose, 8.5–10 x 8–10 µm excluding the ornamentation of irregularly amyloid spines up to 2 µm tall, isolated or clustered in groups of 3–4 or with some ridges <1 µm tall connecting the spines to form a partial reticulum. Illustrations — Lebel (2003b: 414, 415).

Gymnomyces pallidus Massee & Rodway — Fruit bodies up to 2 cm broad, smooth but with patches of pubescence, with a yellowish brown peridium and a cream coloured to light brown gleba. The hymenium contains frequent, prominent, acicular cystidia. Spores globose to subglobose, 7–9 (–10) µm excluding a low ornamentation of scattered warts and short lines; the sterigmal attachment is larger than for most *Gymnomyces* species (1–2 µm tall and broad) and on many spores is strongly amyloid or with heavy amyloid deposits at the base. Illustrations — Pegler & Young (1979: 376); Lebel & Trappe (2000: 1196, 1197); Lebel & Castellano (2002: 338).

Gymnomyces pterospermus T. Lebel — Up to 4 cm broad, this species has a smooth, dry, white peridium mottled with brown and an ivory to brownish gleba mottled dark brown in age. The globose spores are 9.5–13 µm broad and distinctive for their amyloid ornamentation of branched, ragged ridges that form a reticulum 2–4 µm tall and 1 µm thick. Illustrations — Lebel (2003b: 418, 419).

Gymnomyces westresii T. Lebel — Peridium dry and initially pale yellow, later developing orange to brick red or brown streaks and patches while the underlying yellow colour deepens. Gleba pale yellow, sometimes with brown zones, with small locules. Illustrations — Lebel (2003b: 422, 423).

Hydnangium glabrum Rodway — This species will be transferred to *Arcangeliella* as yet another member of the smooth, orange, species complex. It closely resembles *A. australiensis* but has spores 7–9 (–10) µm broad and lacks cystidia on the peridium. Illustrations — Cunningham (1944: plate xxxiii), as *Octaviania glabra.*

Leucogaster meridionalis G.W. Beaton, Pegler & T.W.K. Young — This species is pure white outside and in. The gleba has round chambers up to 1 mm broad that, when fresh and moist, exude a sticky, white suspension of spores in a fluid derived from autolysis of basidia and possibly other cells. In old or dry specimens, the spore mass is dry and fills the locules. Illustrations — Beaton *et al.* (1985d: 830, 831).

Russula albidoflava T. Lebel — A sequestrate *Russula,* this species resembles *R. rostraticystidia* macroscopically, but its white peridium develops a yellowish tinge. Its spores are subglobose to broadly ellipsoid, 7.5–10 x 7–8.5 µm and ornamented with an amyloid, partial to almost complete reticulum of fine ridges and scattered, isolated warts, all <0.5 µm tall. Cystidia 25–31 x 7–10 µm, clavate to cylindrical. Illustrations — Lebel & Tonkin (2007: 363, 364).

Russula rostraticystidia T. Lebel — The sequestrate fruit bodies are up to 25 x 15 mm, globose to flattened, the margin of the cap incurved to form an indented base, ivory-white and smooth but with fine, felty white patches and brownish stains. Gleba white, becoming ivory, with small, crowded chambers. Stipe-columella white with brown stains, up to 3 mm broad, percurrent. Spores globose to subglobose, 6–9 µm broad, ornamented with an amyloid, partial to complete reticulum <0.5 µm tall. Cystidia 48–75 (–100) x 4–12.5 µm, ventricose to cylindrical and elongated rostrate. Illustrations — Lebel & Tonkin (2007: 374, 375).

GLOMEROMYCOTA

[Diversisporales]

New genus G pulvinatum — Molecular studies by Redecker *et al.* (2007) indicate that *Glomus pulvinatum* should be placed in a new genus. The small sporocarps are initially white from a usually well developed peridium that becomes brown in age. Gleba a mass of spores and hyphae without any organised structure. Spores mostly subglobose to globose, 65–105 µm broad, hyaline to subhyaline, thin-walled, with a hyphal attachment 8–15 µm broad that is closed by a septum. Illustrations — Thaxter (1922: plate 2), as *Endogone pulvinata*; Redecker *et al.* (2007: 38).

[Glomerales]

Glomus australe (Berk.) S.M. Berch & Fortin — Fruit bodies firm, globose with a white to pale yellow or pale brown peridium and a fibrillose to felty surface. Gleba a mix of loose, white hyphae and large, dark brown, spherical spores easily visible with a hand lens. Spores up to 0.3 mm broad, with thick walls and a broad, attached hypha. Illustrations — Berch & Fortin (1983: 2613), McGee & Trappe (2002: 119).

Glomus microcarpum Tul. & C. Tul. — Fruit bodies a firm mass of spores in a matrix of white hyphae enclosed in a white to brown peridium. The spores, borne on the tips of hyphae, are hyaline to pale yellow, globose to variously shaped and range from 25 x 25 to 55 x 32 µm. Spore walls up to 7 µm thick. Illustrations — Tulasne & Tulasne (1851: plate 20), Bucholtz (1912: 192) and Thaxter (1922: plate 2), all as *Endogone microcarpa.*

ZYGOMYCOTA

[Endogonales]

Endogone neglecta Rodway — Fruit bodies mostly 3–6 mm broad, subglobose, pale, fleshy or almost waxy-floccose. Spores globose, 32–53 µm broad, with two hyaline walls, the outermost being ± 5 µm thick, the inner ± 2 µm thick. No hyphal attachments to spores could be found in the holotype, the only extant collection of this species. However, occasional spores had what could be interpreted as attached but collapsed gametangia. The generic placement of this species remains tentative until new material is found.

ROYAL SOCIETY OF TASMANIA PAPERS AND PROCEEDINGS
INSTRUCTIONS TO AUTHORS

The Royal Society of Tasmania, which was founded in 1843, is the oldest scientific society in Australia and New Zealand and the third oldest Royal Society in the Commonwealth. Since 1849 it has published annual volumes of refereed scholarly papers about Tasmania in the *Papers and Proceedings of the Royal Society of Tasmania* and, from time to time, monographs and special, generally thematic, issues of the journal. Its subscribers include learned societies, research institutions and universities all over the world.

Scope

Papers and Proceedings of the Royal Society of Tasmania publishes research that focuses on Tasmania or is particularly relevant to Tasmanians. Although the subject matter is usually within the natural sciences or history, papers in the arts, social sciences or other disciplines are encouraged. Papers should embody the results of a significant piece of original work or offer an original synthesis or review.

Papers may be submitted by members of the Society or by non-members. Submission implies that the contents are original and have not been published previously in any form, and that no similar manuscript will be submitted elsewhere.

Copyright

Verbatim quotations of text must be acknowledged and the source given (with the relevant page number/s). Authors must specifically acknowledge the source of illustrations that have been previously published elsewhere and are not their property, and must obtain permission for publication of text or illustrations covered by copyright. Permission to use material previously published by the Royal Society of Tasmania can be obtained upon application to the Council.

Address for submissions

Honorary Editor, The Royal Society of Tasmania, GPO Box 1166, Hobart, Tas 7001, Australia. Should you wish to submit your paper electronically, enquire via the Royal Society at royal.society@tmag.tas.gov.au as to the email address of the Honorary Editor.

Please include your email address and the name of the person the editor can contact with editorial queries, proofs, etc.

Refereeing policy

The Council of the Society will take into consideration the advice of at least two reviewers before deciding for or against accepting the paper for publication. That decision will be final. If the paper is not accepted, one copy will be retained by the Society, the others returned to the author. Once accepted, papers and their copyright belong to the Society. However, an author may copy his or her paper for distribution as a reprint, and reproduction of synopses in abstracting journals is authorised. PDF files are available for purchase by authors.

Style

Referees are not expected to correct grammatical or spelling mistakes; papers should be well written, with the minimum of jargon. Remember that many of the readers of this journal are not specialists in your field; do not exclude them.

The Editor reserves the right to adjust the text for clarity, conformity to style, and publication standards. In general, the Editor follows the conventions in the current edition of the *Style Manual for Authors, Editors and Printers* published by the Australian Government Publishing Service, and the spelling in the *Macquarie Dictionary*.

Text format

- use 11 or 12 point serif type
- print double-spaced (not one-and-a-half spaced) for hard copy, but use singe-spaced copy for electronic submission.
- do not justify (i.e. use ragged right)
- number all pages consecutively, including references, figure legends, appendices
- number every fifth line (automatic in Word) to assist reviewers
- send three copies of the paper (including good copies of the illustrations) if submitting in hard copy. If submitting electronically, send one hard copy to the Editor.
- Submit an electronic version of the text (Word) and figures (TIF, JPG, PDF or EPS) with a hard copy submission.
- supply key words (2–10) for the use in abstracting journals
- include an abstract of no more than 200 words

Citation format

- published material e.g., Brown (1983), Brown & Green (1985), Brown *et al.* (1987), Brown *et al.* (in press), (Brown 1983)
- note any information supplied personally to the author(s) e.g., (T.O. White pers. comm.); do not include in the list of references; obtain permission from the informant (preferably in writing) to quote him or her
- include the relevant page number of a lengthy cited work e.g., (1983: 110)
- do not refer to papers "in preparation"; cite these as (author(s) unpubl. data).

References format

The reference list should conform to the format used in recent volumes of the journal. Common examples are as follows:

Single author paper:

Bingham, M. 1998: The distribution, abundance and population trends of Gentoo, Rockhopper and King penguins in the Falkland Islands. *Oryx* **32**: 223–232.

Two author paper:

Hawke, D.J. & Newman, J. 2005: Using isotope analysis to identify incorporation of marine nutrients in terrestrial birds at Snares Islands. *Notornis* **52**: 108–111.

Multiple author paper:

Ainley, D.G., Veit, R.L., Allen, S.G., Spear, L.B. & Pyle, P. 1995: Variations in marine bird communities of the California current, 1986–1994. *California Cooperative Oceanic Fisheries Investigations Reports* **36**: 72–77.

Book:

Davison, A.C. & Hinkley, D.V. 1997: *Bootstrap Methods and their Application.* Cambridge University Press, Cambridge: 592 pp.

Edited work:

Marchant, S. & Higgins, P.J. (eds) 1993: *Handbook of Australian, New Zealand and Antarctic Birds. Volume 2: Raptors to Lapwings.* Oxford University Press, Melbourne, Australia: 1048 pp.

Chapter in an edited work:

Artyukhin, Y.B. & Burkanov, V.N. 2000: Incidental mortality of seabirds in the drift net salmon fishery by Japanese vessels in the Russian Exclusive Economic Zone, 1993–1997. *In* Kondratyev, A.Y., Litvineko, N.M. & Kaiser, G.W. (eds): *Seabirds of the Russian Far East.* Canadian Wildlife Service Special publication, Ottawa: 105–116.

Thesis:

Charleton, K.J. 2002: Variation in Sooty Shearwater burrow entrance density, burrow use and chick emergence: Science and Traditional Environmental Knowledge approaches. Unpublished MSc thesis, University of Otago, Dunedin.

Electronic version of journal:

Chiswell, S.M. & Rickard, G.J. 2006: Comparison of model and observational ocean circulation climatologies for the New Zealand region. *Journal of Geophysical Research* **111**: C10011, doi: 10.1029/2006JC003489.

Website:

IUCN 2001: *IUCN Red List of Threatened Species 2001 Categories & Criteria (version 3.1),* www.iucnredlist.org (accessed 22 January 2007).

Report:

MacKenzie, D.I. & Fletcher, D. 2005: Characterisation of seabird captures in NZ fisheries. Report to Ministry of Fisheries for Project ENV2004-04. April 2006. Unpublished Report to the Ministry of Fisheries, Wellington: 99 pp.

PLEASE NOTE that an en-dash should be placed between page numbers NOT a hyphen.

Tables and Illustrations

- number consecutively in the order of the first reference to them in the text

Tables

The preferred dimensions for tables are either (a) 65 lines or less in depth, each line of no more than 130 characters and spaces in length, or (b) 42 lines or less in depth, each line of no more than 190 characters and spaces. These dimensions include the title, explanatory material and column headings.

- tables should be "stand-alone", with sufficient information for the table to be understood without reference to the text.
- explain symbols and abbreviations (e.g., n.d. = no data) in the footnotes to the table which should be superscripted by sequential numbers.
- should have the fewest possible lines; do not use the grid "default" in *Word*

Illustrations (figures and plates)

The maximum dimensions for illustrations, when printed, are 250 by 167 mm, including captions. Wherever possible, illustrations will be fitted into a single column (width 80 mm). Illustrations:

- preferably in black and white; colour illustrations may be used but authors will be expected to bear the extra cost of printing
- supply captions for all illustrations.
- use keys within the artwork to explain symbols used in the illustrations
- add bar scales or objects of known or stated dimensions to show the scale of illustrations wherever appropriate
- write the author's name and the figure or plate number in soft pencil on the back of each illustration
- lines, letters and symbols must be of a size and weight to stand the likely reduction to the printed size without breaking up, becoming too faint, filling in or becoming too small for ready legibility; the smallest letter or number, after reduction, should be not less than 2 mm high and, on the axes of graphs, 2.5 or 3 mm high.
- electronic figures should be made available in TIF, JPG, EPS or PDF formats. **DO NOT EMBED ILLUSTRATIONS (FIGURES AND PLATES) IN A WORD OR POWERPOINT DOCUMENT. THEY LOSE RESOLUTION AND ARE DIFFICULT TO RETRIEVE.**

Appendices

Material presented as Appendices (labelled 1, 2, 3, etc.) is accepted at the editor's discretion, but may be printed in a smaller type than the body of the paper.

Conventions

The Botanical, Zoological and Stratigraphic Codes of Nomenclature should be fully observed.

Use of SI units of measurement is strongly preferred where consistent with the means of measurement.

Costs

To keep publication costs down, texts should be concise, and tables and illustration should be used sparingly, both for economy and for maximum effect in the published form. Grants from author's institutions or elsewhere to support publication should be secured if possible. Authors are responsible for the costs of changes, other than minor corrections, to proofs. Page charges will normally be levied on the eleventh and each subsequent page of a paper as printed. The author will be charged the cost of printing colour illustrations.

Museum Victoria
71422

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 142, PART 2

Contents

page

Kiernan, K. & McConnell, A. — Periglacial processes on Heard Island, Southern Indian Ocean 1

Pemberton, D., Gales, S., Bauer, B., Gales, R., Lazenby, B. & Medlock, K. — The diet of the Tasmanian Devil, *Sarcophilus harrisii*, as determined from analysis of scat and stomach contents 13

Sutherland, F.L., Barron, B.J., Pogson, R.E., Everard, J.L., Forsyth, S.M. & Hollis, J.D. — Unusual pegmatoid crystallisations in a nephelinite plug, near Round Lagoon, eastern Central Plateau, Tasmania 23

Osborn A.W., Forteath, G.N.R. & Stanisic, J. — A new species of freshwater sponge (Porifera:Spongillidae) of the genus *Radiospongilla* from Lake Pedder in Tasmania 39

Dartnall, H.J.G. — Antarctic vignettes I: Mawson's sailmaker – James Forbes 45

Dartnall, H.J.G. — Antarctic vignettes II: The search for S. Tasman, AB, on the *Terra Nova*, 1903–04 47

Kantvilas, G., Elix, J.A. & Jarman, S.J. — A contribution to an inventory of lichens from South Sister, northeastern Tasmania 49

de Little, D.W., Foster, S.D. & Hingston, T.L. — Temporal occurrence pattern of insect pests and fungal pathogens in young Tasmanian plantations of *Eucalyptus globulus* Labill. and *E. nitens* Maiden 61

Nicolle, D., Potts, B.M. & McKinnon, G.E. — *Eucalyptus cordata* subsp. *quadrangulosa* (Myrtaceae), a new taxon of restricted distribution from southern Tasmania 71

Johnson, K. A., Whinam, J., Buchanan, A. M. & Balmer, J. — Ecological observations and new locations of a rare moss, *Ambuchanania leucobryoides* (Ambuchananiaceae) 79

Trappe, J.M., Bougher, N.L., Castellano, M.A., Claridge, A.W., Gates, G.M., Lebel, T. & Ratkowsky, D.A. — A preliminary census of the macrofungi of Mt Wellington, Tasmania – the sequestrate species 85

Instructions to authors 97

S1533